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Reducing Nutrient Runoff From Poultry Production Facilities Using Locally-Sourced Iron and Aluminum Byproducts

Sheri Lynn Herron
University of Arkansas, Fayetteville

Reducing Nutrient Runoff From Poultry Production Facilities
Using Locally-Sourced Iron and Aluminum Byproducts

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By

Sheri Lynn Herron
San Diego State University
Bachelor of Arts in Natural Resource and Environmental Geography, 1994
University of Arkansas
Master of Science in Agronomy, 1998

July 2015
University of Arkansas

This dissertation is approved for recommendation to the Graduate Council.

_____
Dr. David M. Miller
Dissertation Director

_____
Dr. Andrew N. Sharpley
Committee Member

_____
Dr. Kristofor R. Brye
Committee Member

_____
Dr. Greg Thoma
Committee Member

_____
Dr. Mike B. Daniels
Committee Member

_____
Dr. Susan E. Watkins
Committee Member

_____
Dr. Andy Pereira
Committee Member

ABSTRACT

Phosphorus (P) inputs to fresh waters can accelerate the eutrophication process. Agricultural nutrient runoff has been shown to be a contributor of P and nitrogen (N). Broiler production areas were evaluated for their potential to contribute P and N to runoff. Broiler house dust (BHD) samples were analyzed and compared to broiler litter (BL), rainfall simulations were conducted on plots adjacent to broiler house fans to evaluate nutrient enrichment in runoff from deposited dust, and runoff was automatically sampled at two culverts draining the land around broiler houses. Following this, an on-farm byproduct containment and nutrient removal structure was designed to reduce concentrations of P and N in runoff from land adjacent to fan outlets. The BHD ranged in water extractable phosphorus (WEP) concentrations from 4,720 to 6,580 mg kg^{-1}, which was at least 1.6 times greater than the BL from which it originated. Water extractable P has been shown to be the most consistent and reliable indicator of P runoff potential. Runoff concentrations from plots adjacent to fans ranged from 2.3 to 16.6 mg L^{-1} total P (TP) and 15.0 to 122.3 mg L^{-1} total N (TN), and were comparable to those from pastures to which large quantities of BL had been applied. To evaluate for their potential use in the nutrient removal structures, iron filter cake (RM) and aluminum water treatment residual (WT) were tested for their P adsorption capacities and hydraulic conductivities. Phosphorus removal study results revealed an average of 56 and 57% were removed by the $\leq$6-mm fraction treatment combination of RM and WT, respectively, and both transmitted sufficient flow to accommodate a 25-fold 25-year 30-minute storm of 5.5 cm min^{-1}. Data compiled for four on-farm containment structures for 25 storm events show reductions in TP concentrations to an average of less than 0.90 mg L^{-1} for RM and 0.40 mg L^{-1} for WT. Phosphorus and N concentrations are elevated in runoff both at the nutrient source and at the edge of the production area. Nutrient removal at the source is an efficient method to reduce these concentrations.

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CHAPTER 1

INTRODUCTION

INTRODUCTION

Problem Statement

Nutrient enrichment remains a major impairment to the designated uses of fresh and coastal waters of the United States (Schindler et al., 2008). While there are many sources of nutrients, point sources are generally easy to identify and quantify and are, therefore, theoretically easier to control. However, nonpoint sources are far more difficult to quantify and control. The contribution of agriculture, in particular intensive livestock and crop production, to the nutrient enrichment of surface waters has received increased attention from government agencies, non-governmental organizations (NGOs), and the public in general (U.S. EPA, 2010). The U.S. Environmental Protection Agency (EPA) recently increased its focus on the potential point source pollution consisting of dust and feathers exhausted through fans from broiler production houses and the resulting nutrient discharges into waters of the United States (Alt, et al v EPA, et al, 2013). The production houses to which EPA is referring include broiler chickens, broiler egg-laying hens, and turkeys, all produced on dry bedding. The bedding is typically comprised of wood shavings, rice hulls, peanut hulls, sand or a combination of these.

In response to both large- and small-scale nutrient runoff, recent United States Department of Agriculture (USDA) and EPA initiatives have focused on the implementation of conservation measures or best management practices (BMPs) to achieve targeted nutrient loss reductions from agriculture on a large scale in the Mississippi River Basin (MRB) and Chesapeake Bay Watershed (CBW) (USDA NRCS, 2011). On a smaller and more focused scale, the EPA has been sampling soils and rainfall runoff water around broiler production facilities in the Illinois River Watershed in northwest Arkansas and northeast Oklahoma, and using the results to encourage independent producers to implement management strategies to reduce nutrient discharges from their facilities.

Producing 1.04 billion birds per year, Arkansas is second only to Georgia (1.31 billion birds per year) in broiler production (US Census Bureau, 2012). The majority of this production is located in northwest Arkansas and northeast Oklahoma. Water quality issues locally (i.e., lawsuits with Oklahoma) and regionally (i.e., Gulf of Mexico hypoxia) are necessitating greater nutrient management and loss controls in northwest Arkansas and northeast Oklahoma than in other areas. As a result, broiler

producers in this area are under increasing pressure from regulatory agencies to control nonpoint source nutrient runoff not only from fields where litter (i.e. manure and broiler house bedding) is used as fertilizer, but also potential point source nutrient runoff from their production facilities. Independent broiler producers are not currently required to have National Pollution Discharge Elimination System (NPDES) permits for their production facilities due to an agriculture exemption; however, there is much discussion regarding a requirement in the future since the nutrients from the production facilities are not managed under a nutrient management plan as required to qualify for the exemption (Clean Water Act, 1972). It has been suggested that a possible alternative to permitting the facilities could be implementation of nutrient management plans, which would include utilizing BMPs to reduce sediment, phosphorus (P), and nitrogen (N) in stormwater runoff from around the production facilities.

Sources of nutrients at broiler production facilities originate from inside the houses that confine the animals. The nutrients from manure and spilled feed are sorbed to particulate matter, which exits the broiler houses through ventilation fans and from the tires of skid steers tracking litter from the broiler house floor during bird removal and litter cleanout. The dust is comprised of the fine particulate portion of broiler litter and is a combination of feathers, fecal material, skin, spilled feed, mold spores, bacteria, fungus, and bedding fragments [e.g., rice hulls (silica and lignin) and pine wood shavings (cellulose fibers and lignin)] (Wicklen and Czarick, 1997). This dust accumulates on the roofs of the houses and on the grassed areas below the fans. The litter that is tracked out is deposited on the concrete and gravel pads outside the house. During rainfall, particulates and nutrients can be carried away from these sources in runoff.

While nutrient management plans have created better control measures for nutrient runoff from pastures receiving litter, deposited dust and tracked litter are more difficult to control. Currently there are no existing BMPs being used other than grassed drainage swales between the broiler houses and grassed embankments at the ends of houses that provide some infiltration of rainfall runoff water and trapping of nutrients in the soil. The grassed areas are mowed regularly, but the grass and nutrients are not harvested and are allowed to accumulate and potentially be released to rainfall runoff leaving the production area.

Objectives

The first objective of this project was to quantify nutrient enrichment of rainfall runoff from soil covered with ventilation fan dust and tracked litter from broiler production facilities. This was done using rainfall simulation on grassed plots adjacent to broiler house ventilation fans to determine the concentrations of nutrients in runoff from adjacent to the fans, where dust had been deposited. Sampling was also conducted at the drainage culverts where rainfall runoff exits the production facility, in an effort to quantify the inputs from tracked litter and the concentrations of nutrients in runoff as it leaves the production area. These measurements provided the necessary information to establish the most effective location for nutrient reduction practices.

The next objective was to evaluate the effectiveness of using iron “filter cake”, a byproduct of tire steel belt production, and aluminum “sludge”, a byproduct of drinking water treatment, to adsorb eutrophying nutrients found in broiler house dust and litter. Since the primary concern in the accelerated eutrophication of freshwater systems is P, the P adsorption characteristics of the byproducts were evaluated in laboratory experiments using monopotassium phosphate prior to evaluation of their N and P sorption capacities when treated with broiler house dust and exposed to simulated rainfall.

The final objective was to develop a cost-effective and simple method for on-farm use of the byproducts to reduce nutrient concentrations in rainfall runoff. This included design and on-farm testing of a containment structure for the byproducts.

Practical Implication of Results of the Project

Results of this project will provide potential (at exhaust fan sites) and actual (at drainage culverts) nutrient runoff concentrations and loads for the University of Arkansas’ Savoy broiler production facility. Although the data are specific to this facility and its management conditions, it is possible to extrapolate the data to other facilities for site-specific nutrient management.

Testing of the iron and aluminum byproducts for their effectiveness in sorbing nutrients from broiler house dust will be useful for current and future design methods for on-farm nutrient reduction practices. For instance, there are numerous ways in which the byproducts can be used for various

agricultural applications, such as containment in ponds, containment to intercept runoff in drainage swales, and land application at nutrient sources.

Designing and testing a containment structure for the iron and aluminum byproducts allows for demonstration and validation of a new technology. This technology must be simple to install and maintain to offer broiler producers an option to reduce nutrient concentrations in runoff from their production facilities. Installing the containment structures on the University of Arkansas' Savoy broiler production Facility also allows for evaluation by USDA-Natural Resources Conservation Service for inclusion in their Environmental Quality Incentive Program (EQIP) as a cost-shared item to reduce the cost to the broiler producer.

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CHAPTER 2

LITERATURE REVIEW

LITERATURE REVIEW

Surface Water Quality Impairments from Excess Phosphorus

Many fresh and salt water bodies are impaired by accelerated eutrophication due to human activities, which produce increased nutrient and sediment loads (Bartsch, 1970). Eutrophication restricts water use for fisheries, recreation, industry, and drinking due to the increased growth of undesirable algae and aquatic weeds and oxygen shortages caused by their death and decomposition. Also, many drinking water supplies throughout the world experience periodic massive surface blooms of cyanobacteria (Kotak et al., 1993). These blooms contribute to a wide range of water-related problems including summer fish kills, unpalatability of drinking water, and formation of trihalomethanes, some of which are carcinogenic, during water chlorination (Kotak et al., 1994; Palmstrom et al., 1988). The associated health risks to livestock and humans have dramatically increased public awareness of eutrophication and the need for remedial action (Burkholder and Glasgow, 1997).

Phosphorus (P) inputs to fresh waters can accelerate eutrophication (Carpenter et al., 1998, 2008; Schindler, 1977; Schindler et al., 2008). Although nitrogen (N) and carbon (C) are also essential to the growth of aquatic biota, most attention has focused on P. Because of the difficulty in controlling the exchange of N and C between the atmosphere and water, and fixation of atmospheric N by some blue-green algae, P is often the nutrient which limits biological productivity in fresh water bodies. Thus, control of P inputs is critical to reducing freshwater eutrophication. For water bodies with naturally greater salt content, as in estuaries, there are likely unique, site specific, critical concentrations of both N and P that generally limit aquatic productivity (Howarth et al., 2000).

Recent modeling efforts and surveys have suggested that agriculture is a major contributor of nutrients to surface waters and thereby to their impairment (Kovzelove et al., 2010; USDA-NRCS, 2010 and 2011a). For example, recent model estimates suggest that up to 85 percent of the N and P entering the Gulf of Mexico, via fresh water rivers and lakes, originates from agriculture and that Arkansas is the fourth largest contributor (Alexander et al., 2004, 2008). Modeling nutrient fluxes in the Illinois River Watershed (IRW) in northwest Arkansas and northeast Oklahoma indicates that there are two primary contributors of excess P to the regions' surface waters: sewage treatment plants (point source) and

animal agriculture (nonpoint source) (Storm et al., 2010). These estimates are based on modeling of the large-scale watershed, since there are few small-scale studies because actual field-scale losses of N and P from agricultural production systems are difficult and expensive to measure. Even so, these predictions have been used to target about $30 million of cost-shared best management practices (BMPs) to agriculture in Arkansas between 2011 and 2015 (USDA NRCS, 2011b).

To better allocate limited funding to reduce excessive nutrient inputs, U.S. Environmental Protection Agency (EPA) is looking to increase the development of Total Maximum Daily Loads (TMDLs) or “pollution budgets" to restore waters that are impaired (US Environmental Protection Agency, 2011). TMDLs are difficult to establish due to the complexity of stream, river and lake ecosystems, as well as the challenge of managing water bodies for competing uses (i.e., fishing versus drinking water quality). EPA is currently developing a model to establish TMDLs for the IRW in northwest Arkansas and northeast Oklahoma (US Environmental Protection Agency, 2009).

Agricultural Phosphorus

Point and Nonpoint Sources

Since the late 1960's, point sources of water pollution have been reduced due to their ease of identification and the passage of the Clean Water Act (CWA) in 1972. The CWA created the permitting system for point sources known as the National Pollutant Discharge Elimination System (NPDES) to regulate discharges from industrial facilities (e.g., manufacturing, oil and gas), municipal government facilities, and confined animal agricultural facilities (e.g., beef and dairy feedlots). Discharges are regulated according to basic national standards without regard to the receiving water body unless the receiving water body is determined to be impaired, in which case water quality-based limitations are implemented based on impairment to designated uses (Clean Water Act, 1972). The CWA has historically focused its regulatory authority over agriculture on liquid manure systems, which were thought to pose a greater threat to surface water than dry manure systems due to the potential for the liquid to be more easily transported in runoff to surface waters.

Point sources of agricultural nutrients include animal waste lagoons, from which manure can be transported if the catchment overflows from excessive inputs or from stormwater overloads. Additional

sources include surface irrigation of liquid manures and runoff from animal feedlots. These sources are regulated through strict design standards under NPDES permits and fines to the producer if discharge occurs (Parry, 1998).

Although N and P concentrations from point sources have been reduced, water quality problems remain, and as further point-source control becomes less cost-effective, attention is being directed towards the role of agricultural nonpoint sources in water quality degradation (Duriancik et al., 2008; Hilton et al., 2006). In a 1996 EPA report, nonpoint-source nutrients were the primary source of concern in 40 percent of rivers, 50 percent of lakes, and 60 percent of estuaries surveyed and listed as impaired (U.S. Environmental Protection Agency, 1996). This situation has changed little since then (Dubrovsky et al., 2010; Sprague et al., 2009; U.S. Environmental Protect Agency, 2010).

Nonpoint sources include surface application of liquid and dry manures using field spreaders, defecation from free-grazing cattle, and dust exhausted and manure tracked from confined animal production facilities. These sources are challenging to control due to the difficulty in identifying the pathways that are involved and quantifying their direct impacts on surface water (U.S. Environmental Protection Agency, 2003).

Nutrient Transport from Animal Manures

Literature regarding the movement of dust and tracked manure from animal production areas is limited because these residuals are not intentionally spread on areas directly adjacent to the houses and have historically not been considered a significant source of nutrients. Therefore, they have not been assessed for their potential environmental impact. However, extensive research has been conducted on grassed plots, where litter and manure have been applied and rainfall simulators are used to create runoff.

The primary factors controlling nutrient runoff from land to water bodies are the source of nutrients (soil, manure and fertilizer) and means of transport (runoff, infiltration, and erosion) (Daniel et al., 1998; Lemunyon and Gilbert, 1993). Dissolved P movement is controlled by surface runoff, while particulate P is transported by erosion. Surface runoff is the dominant mechanism for P transport from agricultural land (Sharpley et al., 1993; U.S. Environmental Protection Agency, 2003).

Research has confirmed that runoff from land to which broiler litter has been surface applied can elevate P and N concentrations in surface waters (Edwards and Daniel, 1993; Nichols et al., 1994). Broiler litter averages 31 percent moisture content (USDA Animal Waste Management Field Handbook, 2008) and is considered dry manure, which when spread on fields does not runoff without added moisture from rainfall or irrigation. Additional studies have found elevated concentrations of P in runoff from plots treated with swine manure (Smith et al., 2001; Smith et al., 2004), which averages 90 percent moisture content (USDA Animal Waste Management Field Handbook, 2008). Thus, regardless of the type or moisture content of the manure, N, and P can be transported in runoff and have the potential to impact surface water quality.

The present study focuses on dust and tracked manure around production areas. Therefore, the literature reviewed emphasizes the findings from studies on broiler litter since its moisture content and transport characteristics are more similar to those of dust and tracked manure than to those of liquid manures. Further, there is a predominance of broiler operations in the area of concern, the litigated IRW in northwest Arkansas and northeast Oklahoma, compared with dairies and hog operations producing liquid manures.

Poultry production in Arkansas ranks second nationally behind Georgia (National Agricultural Statistics Service, 2014; United States Census Bureau, 2012). The poultry litter generated by this industry has been an invaluable source of nutrients and organic matter to area pastures for over six decades (Risse et al., 2006; Schwartz, 1991; Sharpley et al., 2007). Historically, poultry litter has been land applied based on the N requirements of the locally grown forage crops. This has resulted in the application of up to four times more P than annual forage requirements, a consequent build-up of surface soil test P, and increased potential for P enrichment of runoff from pastures continually fertilized with poultry litter (Sharpley et al., 2007). In Arkansas, this has led to the designation of Nutrient Surplus Areas, which require nutrient management planning prior to land applying any litter (Slaton et al., 2004). The nutrient management planning process determines the risk of P loss from each field on a farm and recommends an appropriate litter application rate and the BMPs needed to minimize the risk of P loss. However, less attention has been given to the potential for nutrient loss from around the poultry houses themselves as a result of house cleanout or dust from ventilation fans. As a result, EPA is now looking to

document the importance of this pathway and to determine the potential need for regulations to limit nutrient loss in stormwater runoff.

Form and Pathways of Nutrient Transport

Phosphorus transport in runoff can occur in dissolved or particulate forms. Dissolved P is typically in the form of orthophosphate, which is immediately available for plant uptake (Walton and Lee, 1972). Particulate P is that P which is sorbed to soil particles or bound to organic matter in soil or manure which is transported as sediment by erosion. Particulate P transport from tilled crop land can be significant, but for the pastures and grasslands dominant in northwest Arkansas most P (75 – 90 percent) is transported in dissolved forms (DeLaune et al., 2004; Sharpley, 1997). This not only greatly extends the distance that P can be transported, but because dissolved P is immediately bioavailable, the short-term eutrophic response is much greater compared to particulate P (Sharpley, 1993). Simulated rainfall-runoff from pastures to which litter had been applied at 4.5 Mg ha^{-1} one month earlier contained an average concentration of 2.2 mg L^{-1} dissolved P (Sauer et al., 2000). This application rate is roughly equivalent to a layer of litter as thick as a dime (1 mm). In contrast, dust deposits outside broiler house fans and from spillage and tracked litter can be up to 12 times thicker (S. Herron, personal observation). In rainfall simulations performed by Edwards and Daniel (1993), nutrient concentrations in runoff significantly increased as litter application rates increased.

Due to the large volumes of dust and tracked litter observed at broiler production facilities, transport of nutrients sorbed to particulate matter may contribute significantly to loss of nutrients from production areas. The risk of particulate transport from dust and tracked litter is increased due to the fact that large quantities of dust and tracked litter are deposited adjacent to runoff pathways which carry considerable volumes of rainfall runoff away from the production facilities. With sufficient rainfall intensity, nutrients in both the particulate and dissolved forms are likely to be lost in runoff from these sites. Treatments intended to reduce nutrient concentrations in runoff leaving the production area should, therefore, target both particulate and dissolved forms of nutrients.

Nutrient Sources at Confined Animal Production Facilities

The sources of nutrients found outside the houses on broiler production facilities are dust from fans and litter tracked by equipment during bird catching and litter cleanout. Nutrient management planning has created better controls for timing and rates of litter application to pastures and croplands, but dust deposits and litter tracking occur year-round according to bird production cycles and are not easily controlled.

Dust from broiler production facilities is the fine particulate portion of broiler litter and is a combination of feathers, fecal material, skin, spilled feed, mold spores, bacteria, fungi, and bedding fragments (Wicklen and Czarick, 1997). Broiler bedding used in U.S. production facilities is predominantly rice hulls, wood shavings, or a combination of the two. Dust exits the broiler house through ventilation fans. Fans are operated for different purposes and at different times during a flock production cycle, which greatly affects the amount of dust exhausted by each fan. There are two modes of fan operation, desired room temperature (DRT) and minimum ventilation. Fans are operated for DRT to reduce the temperature in the house, and are operated for minimum ventilation when DRT is suitable and to provide the required air quality needed by the birds. Thus, the amount of dust escaping through fans increases with house temperature, bird activity, and litter disturbance from machinery. Litter and dust also leave the house during bird removal and cleanout when skid loaders track it onto the gravel pad outside the house.

Preliminary analysis by the author of broiler house fan dust shows a similar total P content to litter (about 17 g P kg^{-1}). However, the environmentally sensitive water extractable P (WEP) concentration of dust (6.1 g kg^{-1}) is greater than litter (2.8 g kg^{-1}), suggesting a potentially greater risk for P loss in surface runoff from equivalent amounts of fan dust and litter. Studies in Kentucky show that one broiler house can emit greater than 785 kg of dust annually (Burns et al., 2008).

Tracked litter differs from litter dust, with greater moisture content and larger average particle size. The greater moisture content causes litter to adhere to and pack on tires and be easily tracked. Tracking is greatest during bird catching due to equipment moving in and out of the house over the top layer of litter, known as cake, which is approximately 46 percent moisture versus the litter underlying the

cake which is typically 26 percent moisture (Coufal et al., 2006). Tracked litter is deposited on the concrete and gravel pads outside the house.

The nutrient content of broiler cake currently ranges from 2.8 to 3.6 percent N, and 1.0 to 1.42 percent P, based on annual analyses of samples processed by the University of Arkansas Agricultural Diagnostic Laboratory (University of Arkansas Agricultural Diagnostic Testing Laboratory, 2010).

Phosphorus Transport in and Removal from Stormwater

Phosphorus enriched runoff from agriculture production areas and fields, golf courses, parks, and other locations where organic and inorganic fertilizers are used can lead to eutrophication of streams, rivers and lakes and impair their designated uses. Literature regarding the movement of broiler house dust and tracked litter is limited because these residuals are not intentionally spread on areas directly adjacent to the broiler houses and have not been considered a significant source of nutrients and, therefore, have not been assessed for their potential environmental impact. However, extensive research has been conducted on grassed plots where litter has been applied and rainfall simulators were used to create runoff. Research has confirmed that runoff from land to which broiler litter has been surface applied can elevate N and P concentrations in surface runoff (Edwards and Daniel, 1993; Nichols et al., 1994).

To reduce the potential threat to water bodies, P removal filters are required to bind large amounts of P from contaminated water. The NPDES program, under the U.S. Clean Water Act Section 402, controls discharge of pollutants into navigable waters (U.S. Environmental Protection Agency, 2014). Stormwater discharge permits are issued based on the guidelines of this act. Several options are available for sediment and nutrient removal using the natural landscape, including infiltration trenches and swales, ponds, and constructed wetlands (Winer, 2000). However, on a contract producer broiler facility there is often limited space for stormwater treatment, and cost and ease of maintenance are necessary priorities. Several products are marketed for stormwater sediment control; however, few companies have developed products for removing P and N from stormwater.

Phosphorus Sorption by Fe and Al Oxide Minerals

It is well known that oxide minerals found in soil such as goethite, an iron-bearing oxide mineral, and gibbsite, an aluminum hydroxide mineral, have high P sorption capacities (Torrent et al., 1990; U.S. Geological Survey, 1984). There are several mechanisms by which such minerals react with P, including ligand exchange with hydroxyl groups, sorption to positively charged edge sites, and surface co-precipitation of Fe and Al phosphates on mineral surfaces. The ligand exchange reaction results in the formation of an inner-sphere surface complex in which the orthophosphate anion is covalently bonded to either a Fe or Al atom in the mineral surface. The chemical stability of such a complex may subsequently be enhanced if the orthophosphate forms a second covalent bond with a second Fe or Al atom at the surface. The stability of the resulting binuclear bridging complex effectively removes P from solution permanently. The electrostatic attraction of the orthophosphate anion to doubly-protonated, positively charged surface hydroxyl and edge Lewis acid sites, by contrast, is much weaker and the orthophosphate so bonded may undergo anion exchange reactions with other anions. Co-precipitation reactions, like the reactions resulting in the formation of bi-nuclear bridging complexes, are only very slowly reversible. Finally, the bioavailability of P that has been sorbed through either the formation of an innersphere surface complex or through surface precipitation can be further reduced if additional Fe or Al oxide/hydroxide precipitates form on top of the sorbed P. Where this occurs, the P is said to exist in an occluded state (Sposito, 2010).

Phosphorus Sorbing Byproducts

A large number of materials produced as byproducts from a range of manufacturing, mining, energy production, and drinking water treatment processes are produced, which have the potential to bind P because of their residual concentrations of active iron and aluminum compounds (Callahan et al., 2002; Penn and McGrath, 2011; Vohla et al., 2011). Because of clean air legislation, for example, large amounts of coal combustion byproducts are produced annually by power plants (U.S. Environmental Protection Agency, 1988). Research has shown these byproducts can be used safely to increase soil pH and reduce subsoil acidity (Callahan et al., 2002; Stout et al., 1999; Stout and Priddy, 1996). Recent research also suggests that two of these byproducts—fluidized bed combustion fly ash and flue gas

desulfurization gypsum—can greatly reduce the water-soluble P levels in soils and surface runoff without appreciably reducing plant-available P and plant growth; moreover, the concentration of heavy metals and arsenic in plants and runoff water are not increased (Stout et al., 1998; Stout et al., 2000). Use of these amendments on critical areas in a watershed has the potential to significantly reduce P loss (Stout et al., 1999).

There are several industrial by-products that have the potential to bind large amounts of P by a variety of chemical reactions, depending of the material. These materials include fly ash, steel slag, acid mine drainage residuals (AMDRs), drinking water treatment residuals (WTRs) and flue gas desulfurization (FG) gypsum. Some AMDRs have been shown to sorb appreciable amounts of P (Penn et al., 2011; Dobbie et al., 2009; Fenton et al., 2009; Heal et al., 2005; Sibrell et al., 2009).

Water treatment facilities throughout the United States use aluminum, iron or calcium salts as flocculants during the water purification process. WTRs from the Beaver Water District in Arkansas are a byproduct of using aluminum sulfate to flocculate solids during the drinking water purification process. Water treatment residuals have been studied and found to be effective in reducing P transport in runoff from fields with high soil test P (Haustein et al., 2000). Haggard and Toor (2007) conducted batch equilibrium experiments on the Beaver Water District's WTRs and found a reduction of P in runoff from 250 mg L^{-1} to 0.27 mg L^{-1}. Iron-based WTRs have been found to have an average P sorption capacity ranging from 5.04 to 10.5 g kg^{-1} (Sampson et al., 2009).

The research described in this thesis will be evaluating the use of an iron-based waste from commercial steel belt production and an aluminum based residual from the Beaver Water District, described above. Currently, both by-products are being landfilled at an ever-increasing expense to the producing manufacturer.

Commercially Available Filter Products for Agriculture

A variety of filter products and containment structures for removal of sediment and/or N and P are available commercially. Most products have been designed to meet regulatory requirements for construction stormwater treatment, while few claim to be suitable for agricultural sites. Filtrexx and Imbrium Systems manufacture products that purport to remove sediment, N, and P. Filtrexx

manufactures a product called Filtrexx Nutrient Removal that chemically adsorbs dissolved P and N from stormwater. Faucette et al. (2008) showed 25 and 33 percent removal of nitrate and ammonium, respectively, in addition to 65 and 92 percent reduction in total and dissolved P in stormwater runoff using the Filtrexx product. The filter media is available in wattles and filter socks, which are composed of compost and mesh along with their patented polymer for nutrient removal. Their products are designed for stormwater swales.

Imbrium Systems manufactures a product called SorbtiveMedia, which is an oxide coated reactive media designed to adsorb soluble P. They claim it sorbs and retains P and can reduce concentrations of total P to less than 0.1 mg/L. The product is designed to be used in sand filters or filtration trenches, or can be placed inside other media, such as wattles, to enhance their effectiveness (Perry, 2009).

Conclusions

Extensive research exists on the mobilization and transport of nutrients in runoff from fields receiving broiler litter, however little information is available on the contribution of runoff from around broiler production areas to nutrient loadings of area streams. This lack of data coupled with the large concentration of broiler production facilities in several areas of the U.S., including northwest Arkansas and northeast Oklahoma, the ongoing lawsuits between these States that associate broiler production with water quality impairment, and the sensitivity of area water bodies to increased biological productivity from the addition of P, make it imperative that this potential source of nutrient loading to streams be investigated and, if necessary, cost-effective treatments to reduce P be identified.

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CHAPTER 3

NUTRIENT COMPOSITION OF DUST EMITTED FROM BROILER HOUSES

NUTRIENT COMPOSITION OF DUST EMITTED FROM BROILER HOUSES

Abstract

Research has long been conducted on the potential water quality impairments associated with land application of broiler litter. Until recently, little attention has focused on nutrient losses that might occur from around broiler production houses due to dust emissions. The objective of this study was to characterize the composition of broiler house dust (BHD) and compare BHD composition to that of broiler litter. Dust composition varied significantly between facilities producing for different integrator companies, due to differences in feed and house management. The facility average gravimetric moisture content of BHD was at least 1.9 times lower than the BL from the same facility. The facility average total phosphorus (TP) and water extractable phosphorus (WEP) in BHD were at least 1.2 and 1.6 times greater, respectively, than the BL from the same facility. Extensive research on the fate and transport of nutrients in surface runoff following land application of BL has shown WEP to be the most consistent and reliable indicator of P runoff potential. The facility average total nitrogen (TN) in BHD was at least 3.0 times greater than BL from the same facility. Since both TP and WEP were greater in BHD than in BL, there is a greater risk of P enrichment to runoff from an equivalent mass of BHD, highlighting the need for broiler producers to carefully manage the dust emitted from broiler houses.

Introduction

Broiler house dust emissions have recently gained attention from the U.S. Environmental Protection Agency (EPA) as concerns increase over air and water quality issues associated with broiler production facilities (Alt, et al v EPA, et al, 2013). These concerns center mainly on the release of P and N into the environment as a result of broiler house dust emissions. The broiler production houses to which EPA is referring include broiler chickens, broiler egg-laying hens, and turkeys, all produced on dry bedding. The bedding is typically comprised of wood shavings, rice hulls, peanut hulls, sand or a combination of these. The concentration of broiler operations in northwest Arkansas, second only to Georgia in annual broiler production (U.S. Census Bureau, 2012), has led to intensive speculation and research on the contribution of broiler operations and land application of litter on area pastures to P and N enrichment of surface waters (Herron et al., 2012; Sharpley et al., 2012). Fueled by several ongoing lawsuits, this led to an urgent need for reliable information on the relative contributions of these and numerous other sources of P and N inputs to area streams and lakes at a watershed scale. However, little research has been conducted regarding the composition or fate of the nutrients in dust emitted to the environment from broiler production houses. Dust from broiler production facilities is the fine particulate portion of broiler litter and is a combination of feathers, fecal material, skin, spilled feed, mold spores, bacteria, fungus, and bedding fragments (Wicklen and Czarick, 1997).

Fans at broiler production houses are operated for different purposes and at different times during a flock production cycle, which greatly affects the amount of dust exhausted by each fan. There are two modes of fan operation, desired room temperature (DRT) and minimum ventilation. Fans are operated for DRT to reduce the temperature in the house, and are operated for minimum ventilation when DRT is suitable and to provide the required air quality needed by the birds. Sidewall fan use dominates during cooler weather. Tunnel fan use is greater during warmer weather and each tunnel fan exhausts at a rate that is 2.5 times greater than a sidewall fan, resulting in significantly more dust being exhausted from the house during tunnel ventilation fan use.

An EPA study conducted in Kentucky estimated that a single broiler house emits greater than 785 kg (1,731 lb.) of dust per year (Burns et al., 2008). The U.S. produces approximately 8.4 billion broiler chickens annually for consumer consumption (USDA/NASS, 2012). Considering that there are

approximately 61,301 broiler houses in the U.S., this equates to an estimated 48 million kilograms of dust emitted annually from broiler houses. Image 3.1 shows dust deposited on the ground adjacent to broiler house tunnel ventilation fans, and shows the exposure of the site to natural rainfall and potential runoff from the slope.

While EPA has conducted studies to quantify dust emissions, little data are available regarding the nutrient content of the dust as it relates to water quality impairment. In order to accurately estimate the potential contribution of dust emitted from broiler houses to nutrient runoff, a detailed chemical analysis of the dust is needed. It is likely that the nutrient content of the dust varies depending on bedding type, bedding management between flocks, and integrator feed management as it relates to the manure excreted. Thus, an evaluation of the chemical composition of the dust among facilities representing different integrators is warranted and would also allow for comparison of the composition of dust to that of the litter from which the dust originate. Furthermore, since fans on a broiler production house operate for different purposes and for different lengths of time depending on the season, characterizing the dust at the different fans at a single facility would allow for evaluation of dust composition variability between fans types and fan locations over time. Therefore, the objectives of this study were to characterize broiler house dust and broiler litter composition among various facilities in northwest Arkansas and evaluate the effects of fan type, fan location, and time on dust composition within a single facility. It was hypothesized that the nutrient content of the BHD would vary between contract integrator facilities due to differences in feed composition and house management, and that the BHD composition would be similar to the BL from which it was sourced. It was further hypothesized that there would be no differences in dust composition between fans at the same facility. However, BHD composition from fans at the same facility were expected to vary between seasons due to impacts of house management and weather.

Materials and Methods

Site Description

Representative contract broiler production facilities were identified for each of the three primary broiler producing companies in northwest Arkansas. Sampling dates were established to occur following

bird removal and after at least three flocks of birds had been produced on the same bedding material. The three-flock minimum was established based on personal experience and knowledge that broiler litter, the source of the dust, becomes substantially more uniform in its chemical composition after three flocks have been produced on the same bedding.

As dust is emitted from the houses by ventilation fans, residual amounts settle on fan shutters and bird barriers (i.e. screens on the inside of the fans to prevent birds from entering the fan box). There are two types of fans at broiler facilities, sidewall ventilation fans, which average 227 cubic meters per minute (cm m^{-1}) flow and tunnel ventilation fans which average 566 cm m^{-1} flow. Dust sampling was conducted for both types of fans.

Sampling occurred within three days following bird removal and prior to any washing of the facility to maintain the in-situ integrity of the dust. Sampling was conducted on rain-free days to protect the samples from outside humidity.

Experimental Design

Since every broiler production facility is managed differently for air quality and bird health, this experiment was not intended to be a comprehensive analysis, but rather a survey to establish a baseline comparison between BHD and BL across various integrators. The experiment was a block design, with the independent variable being the integrator company for which the broiler growers produce broiler chickens and the dependent variables being the nutrient content of the BHD and BL. Several discrete samples from each facility were analyzed for replication.

Litter and Dust Sample Collection

Broiler litter samples were collected from the production house prior to litter cleanout by standard sampling protocols that involved collecting 10 grab samples, from the surface to the floor (approximately 15-cm deep), in a zig-zag pattern within the house. Samples were combined, mixed and subsampled to create one representative, composite sample for each facility (Wilson et al., 2006).

A protocol was established for obtaining consistent dust samples. Dust was collected inside the broiler houses from the tops of fan shutters and bird barriers. Since the dust is extremely lightweight and disperses easily unless air movement within the facility is minimal, all fans were turned off while sampling.

Dust from each fan was sampled and stored independently. A 2.5-cm-wide paint brush was used to brush dust into a plastic dustpan with a hollow handle. Samples were stirred in the dustpan with a fine edged paint scraper. The handle of the dustpan was placed inside the sample container and the paint brush was used to sweep the dust into the handle and container. Once filled, sample containers were immediately capped to avoid contamination. Surplus dust from the composite sample in the dustpan was discarded. Prior to sampling at a different fan, all materials were cleaned. If there was not a sufficient amount of dust on shutters or bird barriers to conduct the required analyses (i.e. about 10 g of material), this was recorded and no sample was collected and retained. Sampling for replications of BHD was limited by available dust volume and resulted in five samples from Facility 1, 29 samples from Facility 2, and 10 samples from Facility 3. Additional sampling occurred periodically from the sidewall ventilation fans at House 4 of Facility 2, after each flock for one year. Table 3.1 summarizes the date, fan type samples, and the number of dust samples collected from each facility.

Samples were transported immediately following collection to the University of Arkansas Agricultural Diagnostic Laboratory or shipped to A&L Laboratories, Memphis, Tennessee for nutrient analysis. In all cases, samples were analyzed in triplicate.

Chemical Analyses of Broiler Litter and Broiler House Dust

Total P, calcium (Ca), potassium (K), and magnesium (Mg) were determined by inductively coupled plasma optical emission spectroscopy (ICP-OES) (PerkinElmer Optima 7300, Waltham, MA) after ashing 1.0 g of dry matter in a muffle furnace at 550^{o} C for 4 hours. Ash was then dissolved in 10 mL of concentrated HCl, transferred to 100 mL volumetric flasks and diluted to volume with distilled water (Wolf et al., 2003). Moisture content of broiler litter and broiler house dust were determined by oven-drying (110^{o}C for 6 hours), which was subsequently used for correction of P and N concentrations to an oven-dry basis. Total carbon (C) and total N were determined by dry combustion (Nelson and Sommers, 1996). For both BL and BHD, pH was determined by standard methods (Self-Davis et al., 2009), and WEP was determined by ICP following the national standard method used for poultry litter, which involved shaking a 100:1 mixture of distilled water:dust (by weight) for one hour on an end-over-end shaker (24.2 rotations per minute). The mixture was centrifuged (Beckman Coulter Allegra X-15R, Pasadena, CA) for

20 minutes at 5,250 x *g*, filtered (0.45 µm), and the P was determined by ICP. Water-extractable litter P was calculated as P concentration per unit dry-weight of litter. Ammonium-N and nitrate nitrogen (NO_3-N) associated with the dust and litter were determined following extraction with 2*M* KCl on an autoanalyzer (Skalar SanPlus, Breda, The Netherlands) by colorimetric determination of NH_4-N using salicylic acid and NO_3-N using the cadmium reduction method (Peters, 2003).

Statistical Analyses

Homogeneity of variance was evaluated among facilities for each dust parameter measured. A one-factor analysis of variance (ANOVA) was conducted to evaluate the effect of source facility on the chemical constituents in the dust. A separate one-factor ANOVA was conducted based on a randomized complete block design to evaluate the differences in chemical constituents between dust and BL. The sample groups for dust compared to litter were comprised of the average constituent concentration for each source facility. A one-factor ANOVA was conducted to evaluate the differences in chemical constituents in dust between fan types and among seasons from house #4 at Facility 2. When appropriate, means were separated by least significant difference at the 0.05 level. All relationships are reported as statistically significant at the $p < 0.05$ level unless noted otherwise. Wolfram Mathematica (online beta version 2014, Wolfram, Champaign, IL) was used to conduct the statistical analyses.

Results and Discussion

General Summary of Dust Sampling

Dust quantity varied at each fan and several fans did not contain adequate dust for sampling. Sampling was conducted at Facility 2 first, where more dust accumulated on fan shutters and protective covers than at the other facilities. The variability in fan dust quantity was, based on observations, likely due to differences in shutter and protective cover design. For example, some tunnel ventilation fans were covered only by wire protective covers, while others were covered by shutters. The shutters have more surface area upon which dust can settle. At Facility 1, there were fewer sidewall fans and the tunnel ventilation fans were used for both ventilation and temperature control. Only tunnel ventilation fan shutters contained sufficient dust volumes for composite sampling at this facility (n = 5 total). At Facility 2,

both sidewall ventilation fan shutters and tunnel ventilation fan bird barriers contained sufficient dust volumes for composite sampling (n = 29 total). Additionally at Facility 2, sampling was conducted periodically at four sidewall ventilation fans at House 4 following five production flocks over a one-year period, which began in 2012 and was completed in 2013 (n=20 total). At Facility 3, only sidewall ventilation fan shutters contained sufficient dust volumes for composite sampling (n = 10 total). Tunnel ventilation fans at this facility were covered by wire protective covers, with little surface area for dust to settle. Table 3.1 summarizes the samples collected by facility and location.

Dust Composition Differences among Facilities

The dust composition varied between the facilities sampled, as was expected based on integrator feed blends and house management. Table 3.2 details the minimum, maximum, and variance for the parameters in the dust analyses for each facility. Among the facilities, 5 of 12 parameters measured had significant differences in variances. The parameters with significantly different variances were N and K, with the greatest variances at facilities 1 and 3, C, with the greatest variances at facilities 2 and 3, pH, with the greatest variance at facility 2, and NH_4-N, for which all three facilities had large variances.

Variability in C and K within the population could be related to bedding management and bird excretion locations. Bedding materials contain significant quantities of C and K. When freshly-hatched broiler chicks are placed in the production house, half of the house is closed off with curtains because the birds are small and do not need as much space. Between 10 and 14 days, the curtains are removed. This results in uneven distribution of manure throughout the house. The litter (bedding and feces) in the house is continuously composting, but more rapidly in the half-house where fresh manure is deposited due to the contribution of moisture, C, N, and P that are consumed by the bacteria to create energy. The bacteria decompose large molecules, releasing elements in the bedding. Where greater rates of composting occur, greater quantities of elements in the bedding are available to be adsorbed onto dust particles. Irregularity of TN concentrations between facilities were likely a result of integrator feed composition. Irregularity of N compounds within facilities was likely related to litter composting rates of nitrifying bacteria, as they converted ammonia into nitrite and then into nitrate. Differences in dust pH between facilities were likely a result of integrator feed composition.

The remaining 7 of the 12 parameters had homogeneity of variance, including moisture content, dry matter, P, Ca, NO_3-N, WEP, and percent TP as WEP (Table 3.2). As a result, ANOVA was used for all 12 parameters, since homogeneity of variances an underlying assumption for ANOVA.

All measured dust parameters differed ($p < 0.05$) among facilities (Table 3.3). The moisture content of dust samples within facilities varied by 1.2, 5.1, and 5.4% for Facility 1, 2 and 3, respectively. The means from facilities 2 and 3 were different that the mean from facility 1. It is common to observe variability in humidity within a broiler house and between houses of the same farm, depending on ground moisture outside each house and litter moisture within each house. Facilities are typically constructed by excavating soil from between houses and mounding it where the houses will be constructed to form a raised pad. The remaining lower areas between house pads are graded to create a gentle slope for runoff water to drain away from the production area. If the land between houses is not graded properly for drainage flow, water can pond and raise the humidity of the air adjacent to the houses. When this air is pulled into the house during ventilation, it can raise the humidity in the house, which in turn raises the humidity of the litter and dust. Additionally, if water lines or drinkers are leaking inside a house, the litter moisture content can be elevated, resulting in more localized increases in humidity, which could be observed in dust settled on fans adjacent to the greater humidity region of the house. The moisture content of the dust varied significantly between the different facilities. These differences are likely a result of different ventilation management, as well as outside humidity around the houses. Ponding was observed between houses at Facility 3, which tested the greatest in dust moisture content, and the height of the grass growing between the houses at this facility was over 15 cm, which contributed transpiration humidity near ventilation intakes.

The additional parameters measured in the dust varied significantly between facilities, and these differences were likely due to integrator feed management. Phosphorus, K, NO_3-N, and pH were different at facility 1 compared to those at facilities 2 and 3. Nitrogen and NH_4-N varied between all three facilities. Carbon, and percent TP as WEP were different at facility 3 as compared to those at facilities 1 and 2. Calcium and WEP were different at facility 2 as compared to facilities 1 and 3.

Each integrator company creates a unique feed mixture for broiler chickens, which varies based on bird age, and is designed to promote rapid growth of muscle, the meat produced for human

consumption, while maintaining bird health. Broiler chickens have monogastric digestive systems, which are not efficient at breaking down and absorbing nutrients required for optimum health from a single grain. While corn is the dominant dietary component in broiler feed, other fat and protein sources are added to the feed to provide a balanced diet.

Phosphorus is a macronutrient required for healthy bone and cell growth, however it is not readily absorbed by broilers in its phytate form in corn. Additional P is added to the diet to ensure the birds absorb sufficient quantities. Since P is not easily absorbed, a large amount is passed through the digestive tract of the bird and is excreted. This results in elevated levels of P in the litter and resulting dust. Phosphorus and WEP are the primary contributors to water quality impairment, so evaluating the levels of these parameters in the dust is important when considering the potential contribution of P to runoff from broiler production facilities. Total P and WEP in the dust were greatest at Facility 2. Water extractable P was lowest at facility 3. The differences could likely be explained by comparing dietary contents. However, feed management is proprietary and the integrator companies would not release the information in order to make that comparison.

Composition Differences between Dust and Litter

Broiler house dust is composed of the lighter-weight particles of broiler litter (BL) and feed. The BL particles are detached and transported as a result of bird scratching and ventilation airflow. Loosely-bound, pelletized feed separates into smaller particles when feed augers operate to deliver feed to feed pans. Both BL and feed particles become airborne and transport with ventilation airflow. It was hypothesized that the chemical composition of the BHD would be similar to the BL from which it originated. However, most of the BHD parameters varied significantly from that in the BL from which the dust originated (Table 3.4).

The average moisture content of the BL from each facility was at least 1.9 times greater than the BHD from the same facility. This difference was expected after visually comparing the texture of the BL to that of the BHD. The dust had the appearance of wheat flour, while the litter appeared similar to moist, medium textured compost.

The primary focus of the comparison of BHD to BL was on the parameters known to impair water quality by increasing rates of eutrophication (i.e., P and N). Average BHD TP and WEP were at least 1.2 and 1.6 times greater, respectively, than that in the BL from the same facility. Average BHD TN was at least 3.0 times greater than that in the BL from the same facility. These numbers are concerning when comparing typical BL land application rates to BHD deposition rates. Broiler litter is land applied as a fertilizer to cropland and hayland, while BHD is deposited on the land adjacent to poultry production houses by fan exhaust. The mass of BL applied or BHD deposited onto the land per unit area is essentially the same, 4,483 kg ha^{-1}. However, due to the larger concentrations of P and N in BHD than in BL, the equivalent rate results in larger amounts of P and N in BHD being deposited on the ground and available for transport in surface runoff.

Average BHD C was 1.1, 1.3, and 1.4 times greater than that in the BL from facility 1, 2 and 3, respectively. Average BHD pH was 1.1, 1.1, and 1.2 times lower than that in the BL from facility 1, 2, and 3, respectively. Potassium and Ca did not vary significantly between BHD and BL from the same facility, which supports the original hypothesis.

Dust Composition Differences among Fans within a Single Facility

Combined across sample dates, BHD composition (i.e. moisture content, dry matter, TN, TP, K, and WEP concentrations, and the fraction of TP as WEP) did not differ among fans in House 4 at Facility 2 (Table 3.5). These results indicate that the dust composition was relatively spatially uniform among fans within this single broiler house. This consistency in dust composition among fans indicates that, although fans were installed at different locations along a wall of a house, and they operated at different times and for different purposes throughout a flock, the particulate matter that became airborne and was transported to the fans was uniform. Uniformity of the particulate matter was not expected, since the birds did not occupy the entire house throughout a flock production cycle and, as a result, manure was not deposited uniformly throughout the house.

Combined across fans in House 4 at Facility 2, BHD composition varied somewhat over time. The moisture contents of dust samples collected in January 2013 were greater ($p < 0.05$) than those in April through October 2012 (Table 3.6). This was likely due to decreased ventilation during cold weather

to retain heat and reduce energy costs. The average moisture of the BHD collected in January 2013 was 21.6%, slightly less than the average moisture content of the BL (Table 3.4) However the average moisture content across all of the dust samples from the five flocks, 13.1%, was approximately half that of BL (University of Arkansas, 2012). The K concentrations of dust samples collected in April through August 2012 were greater ($p < 0.05$) than those in October and January. The differences in dust K concentrations was likely a result of dietary changes, based on the type of grains and supplements available.

In contrast to the moisture content and K concentrations, combined across fans, TN, TP, and WEP concentrations in the dust did not differ over time, and averaged 84.5 g kg^{-1}, 12.6 g kg^{-1}, and 6,002 g kg^{-1}, respectively (Table 3.6). Additionally, the fraction of TP as WEP remained relatively constant at almost 50%, irrespective of sample date (Table 3.6, Figure 3.1).

Conclusions

The nutrients that contribute to increased rates of eutrophication in rivers and lakes, P and N, are present in BHD. There were distinct differences among integrator producer facilities in nutrient concentrations of dust collected. This was likely due to differences in dietary mixtures used by integrators, bedding material, and other in-house management protocols that each producer uses. Therefore, facilities producing for different integrators should be evaluated for their unique potential to contribute P and N to stormwater runoff.

Although the concentrations of TP, WEP and TN in BHD varied between facilities, these concentrations were consistently greater in the BHD than the BL from the same facility. Additionally, the moisture content of the BHD was approximately half that of the BL from the same facility. Due to the variability of moisture content, TP, WEP, and TN between BHD and BL, research that has been conducted on BL to evaluate nutrient transport in stormwater runoff cannot be considered equivalent to using BHD. Therefore, it is important to evaluate the chemical composition, volume, and weight of BHD exhausted from fans, and to assess the potential environmental impacts of its transport to waterways.

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Table 3.1. Summary of Dust Sampling for Each Facility

Facility	Date Sampled	Production House	Fan Type	Number of Samples
1	10/5/2011	1	Tunnel	1
	10/5/2011	2	Tunnel	1
	10/5/2011	3	Tunnel	1
	10/5/2011	4	Tunnel	1
	10/5/2011	5	Tunnel	1
2	9/19/2011	1	Sidewall	4
	9/19/2011	2	Sidewall	4
	9/19/2011	2	Tunnel	7
	9/19/2011	3	Sidewall	3
	9/19/2011	4	Sidewall	4
	9/19/2011	4	Tunnel	4
	4/18/2012	4	Sidewall	4
	6/20/2012	4	Sidewall	4
	8/23/2012	4	Sidewall	4
	10/31/2012	4	Sidewall	4
	1/10/2013	4	Sidewall	4
3	1/9/2012	1	Sidewall	1
	1/9/2012	2	Sidewall	1
	1/9/2012	3	Sidewall	1
	1/9/2012	4	Sidewall	1
	1/9/2012	5	Sidewall	1
	1/9/2012	6	Sidewall	1
	1/9/2012	7	Sidewall	1
	1/9/2012	8	Sidewall	1
	1/9/2012	9	Sidewall	1
	1/9/2012	10	Sidewall	1

Table 3.2. Summary of Minimum, Maximum, and Variance for Dust Composition Among Facilities

Measured Parameter*	Minimum†			Maximum			Variance			Homogeneity of Variance Test (P-value)
	Facility 1	Facility 2	Facility 3	Facility 1	Facility 2	Facility 3	Facility 1	Facility 2	Facility 3	
H_2O (%)	8.6	10.1	12.9	9.8	15.2	18.3	0.2	1.6	2.2	0.47
DM (%)	90.2	84.8	81.7	91.4	89.9	87.1	0.2	1.6	2.2	0.47
N (g/kg)	124.2	69.0	82.2	146.0	91.8	111.8	99.3	34.0	105.4	0.01
C (g/kg)	309.3	286.1	302.0	313.8	345.9	352.7	2.7	346.0	205.9	<0.01
P (g/kg)	13.2	13.6	11.9	15.3	20.6	17.6	0.7	2.2	3.3	0.32
K (g/kg)	38.8	25.5	11.9	47.4	33.1	30.3	9.9	4.2	35.4	<0.01
Ca (g/kg)	15.1	21.2	0.2	16.6	31.5	17.8	0.4	4.5	21.1	0.14
NH_4-N (mg/kg)	8107	2369	4617	10304	3831	5574	842553	155040	84034	<0.01
NO_3-N (mg/kg)	54.7	158.9	167.0	69.4	872.8	1727.0	46.3	39207	205498	0.07
WEP (mg/kg)	5350	4715	3932	6426	8313	5051	233876	722705	130649	0.07
TP as WEP (%)	40.3	27.4	22.5	43.9	54.2	42.4	2.3	38.1	27.4	0.12
pH 1:5	7.0	7.1	7.3	7.3	7.8	7.5	0.009	0.1	0.003	<0.01

* Measured parameters include gravimetric moisture (H_2O), dry matter (DM), nitrogen (N), carbon (C), phosphorus (P), potassium (K), calcium (Ca), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), water extractable phosphorus (WEP), total phosphorus as water extractable phosphorus (TP as WEP), and pH.

† The number of observations included were 5, 26, and 10, from Facility 1, 2, and 3, respectively.

Table 3.3. Dust Composited Differences by Facility

Measured Parameter*	P-value	Facility Means		
		1	2	3
H_2O (%)	<0.001	9.0[a]†	12.6[b]	14.6[b]
DM (%)	<0.001	90.9[a]	87.3[b]	85.3[b]
TN (g/kg)	<0.001	133.3[a]	81.2[b]	101.3[c]
C (g/kg)	0.008	311.8[a]	315.9[a]	335.1[b]
TP (g/kg)	<0.001	14.1[a]	17.2[b]	15.7[b]
K (g/kg)	<0.001	43.6[a]	29.3[b]	24.6[b]
Ca (g/kg)	<0.001	15.8[a]	26.4[b]	12.0[a]
NH_4-N (mg/kg)	<0.001	9227[a]	3223[b]	5257[c]
NO_3-N (mg/kg)	0.021	61.6[a]	402.2[b]	476.7[b]
WEP (mg/kg)	<0.001	5883[a]	6580[b]	4719[a]
TP as WEP (%)	<0.001	41.5[a]	38.5[a]	30.4[b]
pH 1:5	0.002	7.1[a]	7.4[b]	7.4[b]

* Measured parameters include gravimetric moisture (H_2O), dry matter (DM), total nitrogen (TN), carbon (C), total phosphorus (TP), potassium (K), calcium (Ca), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), water extractable phosphorus (WEP), total phosphorus as water extractable phosphorus (TP as WEP), and pH.

† Different lower case letters in a row indicate significant differences among facilities (*$p<0.05$).*

Table 3.4. Broiler House Dust (BHD) and Broiler Litter (BL) Composited Differences by Facility

Measured Parameter*	P-value†	Facility 1		Facility 2		Facility 3	
		BHD	BL	BHD	BL	BHD	BL
H_2O (%)	0.01	9.0	22.6	12.7	26.6	14.7	28.5
N (g/kg)	0.01	133.4	41.9	81.3	27.4	101.3	31.8
C (g/kg)	0.01	311.9	285.6	316.0	251.6	335.2	247.3
P (g/kg)	0.03	14.2	12.1	17.2	13.2	15.7	11.2
K (g/kg)	0.20	43.6	24.8	29.4	23.1	24.7	23.1
Ca (g/kg)	0.79	15.9	17.8	26.5	26.2	12.0	15.1
WEP# (mg/kg)	0.01	5883	2711	6580	2700	4720	2944
TP as WEP (%)	0.02	41.5%	22.4%	38.2%	20.5%	30.0%	26.3%
pH 1:5	0.004	7.1	8.1	7.5	8.5	7.4	8.6

* Measured parameters include gravimetric moisture (H_2O), dry matter (D.M.), nitrogen (N), carbon (C), phosphorus (P), potassium (K), calcium (Ca), water extractable phosphorus (WEP), total phosphorus as water extractable phosphorus (TP as WEP), and pH.

† P-value Result for Effect of Sample Source (BHD vs BL)

Table 3.5. Dust Composition Differences Among Fans at Facility 2, House 4

Fan/Statistic	%		g/kg			mg/kg	% TP as WEP
	H_2O	DM	N	P	K	WEP	
1	13.0	87.0	92.8	11.7	22.5	6406	57%
2	12.5	87.5	81.7	12.1	23.2	5714	47%
3	12.9	87.1	75.9	12.8	21.9	5857	47%
4	14.0	86.0	87.7	13.7	22.6	6031	45%
P-value†	0.97	0.97	0.28	0.88	0.97	0.94	0.08
Overall Mean	13.1	86.9	84.5	12.6	22.5	6002.1	49%

* Measured parameters include gravimetric moisture (H_2O), dry matter (DM), nitrogen (N), phosphorus (P), potassium (K), water extractable phosphorus (WEP), and total phosphorus as water extractable phosphorus (TP as WEP).

† P-value Result for Effect of Fan

Table 3.6. Dust Composition Differences Over Time at Facility 2 (House #4)

Sample Date	H_2O*	N	P	K	WEP	% TP as WEP
	%	g/kg	g/kg	g/kg	mg/kg	
4/18/2012	11.1[a†]	97.8	16.2	25.8[a]	6480	41%
6/20/2012	11.1[a]	79.2	15.7	25.8[a]	7130	46%
8/23/2012	10.9[a]	80.9	14.8	25.5[a]	7926	54%
10/31/2012	10.9[a]	77.1	9.2	18.3[b]	4724	51%
1/10/2013	21.6[b]	87.5	7.0	17.3[b]	3750	53%

* Measured parameters include gravimetric moisture (H_2O), dry matter (D.M.), nitrogen (N), phosphorus (P), potassium (K), water extractable phosphorus (WEP), and total phosphorus as water extractable phosphorus (TP as WEP).

† Different lower case letters in a column indicate significant differences among sample dates (*$p<0.05$).*

Figure 3.1. Facility 2 House #4 Sidewall Fan Dust Total Phosphorus (TP) Concentrations Compared to Water Extractable Phosphorus Concentrations (WEP)

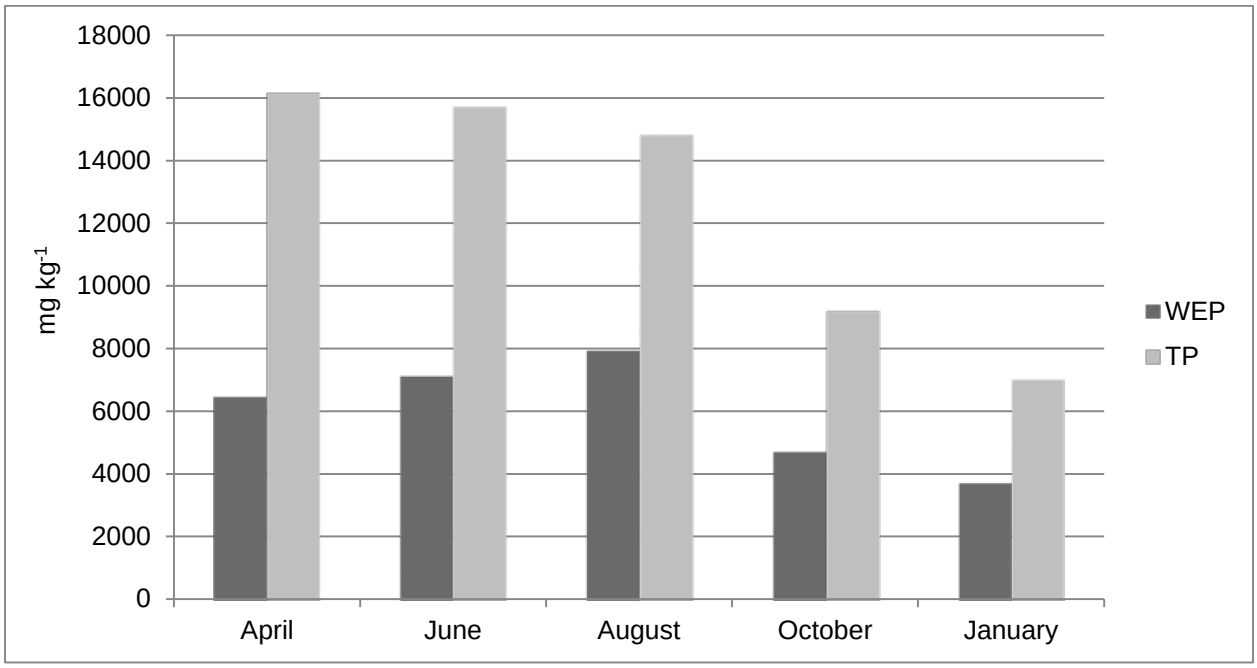

Image 3.1. Dust Deposited Adjacent to Broiler House Tunnel Ventilation Fans

EPA Region 6, 2013

CHAPTER 4

DETERMINATION OF NUTRIENT CONCENTRATIONS IN SIMULATED RAINFALL RUNOFF FROM BROILER HOUSE DUST DEPOSITED ADJACENT TO EXHAUST FANS

DETERMINATION OF NUTRIENT CONCENTRATIONS IN SIMULATED RAINFALL RUNOFF FROM BROILER HOUSE DUST DEPOSITED ADJACENT TO EXHAUST FANS

Abstract

Until recently, little attention has been given to nutrient losses that might occur from around broiler houses due to dust emissions. Rainfall simulations were conducted on 1.5 m by 2.0 m plots to examine the potential for nutrient enrichment in runoff from dust deposited on the ground adjacent to four sidewall and four tunnel ventilation fans of one broiler house at Facility 2. The intent of this study was to evaluate the worse-case scenario of nutrient enriched runoff at the source. Between each flock of birds (approximately every 10 weeks), rainfall was applied at 7 cm hr^{-1} until 30 minutes of surface runoff was collected. Rainfall was applied over a 2-year period; one year on sidewall-fan plots and the second on tunnel-fan plots. Sidewall ventilation fan plots had runoff concentration ranges of dissolved reactive phosphorus (DRP) from 0.3 to 12.2 mg L^{-1}, total phosphorus (TP) from 1.5 to 26.0 mg L^{-1}, ammonium nitrogen (NH_4-N) from 3.6 to 59.1 mg L^{-1}, nitrate nitrogen (NO_3-N) from 3.4 to 55.0 mg L^{-1}, total nitrogen (TN) from 11.0 to 120.6 mg L^{-1}, and total solids (TS) from 245.1 to 1,617.6 mg L^{-1}. Runoff concentrations from tunnel ventilation fan plots ranged in DRP from 0.2 to 7.9 mg L^{-1}, TP from 1.0 to 18.2 mg L^{-1}, NH_4-N from 3.9 to 39.6 mg L^{-1}, NO_3-N from 1.1 to 34.2 mg L^{-1}, TN from 5.1 to 189.0 mg L^{-1}, and TS from 9.3 to 1,249.7 mg L^{-1}. The concentration of P and N in runoff adjacent to side vents was significantly lower ($p < 0.05$) during the warm weather period, which was tested in August, than during the cool weather periods, which were tested from October through June. In contrast, nutrient runoff from tunnel fans was significantly greater ($p < 0.05$) during the warm weather periods, which were tested from May through August, than during the cool weather periods, which were tested from October through April. This reversal was likely due to weather influences which determine the type of fan used and operation duration. Runoff P concentrations were comparable to those from pastures to which large quantities of P (105 kg ha^{-1}) in broiler litter had been applied (>6 Mg ha^{-1} or >3 ton $acre^{-1}$). Based on this study, nutrient concentrations in runoff from plots adjacent to exhaust fans are a potential threat to water quality if the runoff enters a waterway in close proximity to a broiler house.

Introduction

Broiler production facilities in the U.S. are constructed on compacted clay pads with a minimum of two adjacent houses at a facility. Between each house is a depression (or drainage swale) for rainfall runoff to be concentrated and directed offsite. Grass is established in this area for erosion control and to facilitate water infiltration and thereby reduce surface runoff volume and energy.

As stated in Chapter 3, an EPA study in Kentucky reported that a single broiler house can emit greater than 785 kg of dust annually. This study utilized sensors on the fans to measure size and concentration of dust particles prior to being discharged from the house (Burns et al., 2008). The larger particles of dust are heavier and once blown from the house settle on the ground directly in front of the fans. Dust depositions adjacent to fan outlets have been observed at several facilities, but have not been extensively measured due to impacts from variable weather conditions. Limited observations indicate that dust accumulation depths at sidewall ventilation fans can range from 3 to 5 mm, and at tunnel ventilation fans can range from 10 to 25 mm. Based on visual examinations of production facilities on aerial photos, dust deposition can extend 3 to 9 meters from the fan outlet.

Fans are operated for different purposes and at different times during a flock production cycle, which greatly affects the amount of dust exhausted by each fan. There are two modes of fan operation, desired room temperature (DRT) and minimum ventilation. Fans are operated for DRT to reduce the temperature in the house, and are operated for minimum ventilation when DRT is suitable and to provide the required air quality needed by the birds. At Facility 2, sidewall fan 1 (S1) and sidewall fan 4 (S4) operate on a timed schedule at the beginning of each flock during colder weather. Sidewall fan 3 (S3), and S4 operate on a timed schedule at the beginning of each flock during warmer weather. As the birds increase in size they produce more heat. Once the temperature is 1.1 ^{o}C above DRT, all sidewall fans, including sidewall fan 2 (S2), automatically operate simultaneously to maintain house temperature and humidity. Sidewall fan use dominates during cooler weather. When the in-house temperature rises to 1.6 ^{o}C above DRT, tunnel ventilation fan 1 (T1) automatically starts. When the in-house temperature rises to 2.2 ^{o}C above DRT, tunnel ventilation fan 2 (T2) automatically starts. When the in-house temperature rises to 3.1 ^{o}C above DRT, tunnel ventilation fan 3 (T3) automatically starts, and when the in-house temperature rises to 3.3 ^{o}C above DRT, tunnel ventilation fan 4 (T4) automatically starts. Prior to T4

operating, airflow is directed across the house. Once T4 begins operating, airflow is pulled down the length of the house through cooling cells at the opposite end of the house. Tunnel fan use is greater during warmer weather and each tunnel fan exhausts at a rate that is 2.5 times greater than a sidewall fan, resulting in significantly more dust being exhausted from the house.

The objective of this study was to measure P and N concentrations in runoff from dust-deposition sites immediately adjacent to the fans outside the house in order to evaluate the potential for direct transport of this runoff into waterways. The data collected were intended to represent the greatest potential concentrations from the fan-dust deposition from a single flock. The dust deposition pattern allowed for installation of simulated rainfall plots centered over the thickest dust deposits. The sites were covered to avoid disturbance by natural rainfall. Artificial rainfall simulations were conducted after each flock was removed for five flocks to measure concentrations and loads for different seasons over one year for sidewall and tunnel fans.

It was hypothesized that the deposition of broiler house dust adjacent to ventilation fans has the potential to enrich runoff from that area with P and N, as compared to historical runoff collected from pastureland where no poultry-house dust had been deposited. It was further hypothesized that fan type would affect runoff concentrations due to different exhaust rates, resulting in different quantities of dust deposition. Additionally, it was hypothesized that runoff concentrations would vary with fan type seasonally based on fan usage.

Materials and Methods

Study Location

The rainfall simulations were conducted at house #4 at the University of Arkansas Savoy broiler production facility (Facility 2), near Savoy, Washington County, Arkansas. Therefore, the measured data are specific to this house and this production facility.

House #4 at the facility was selected based on the drainage path away from the north side of the house. Runoff from the production area was measured at culverts draining between houses 1 and 2, 2 and 3, and 3 and 4. The land on the north side of house #4 does not contribute to runoff being measured at the culverts (Images 4.1 and 4.2) (Adapted from image from Google Earth, 2012).

The grassed areas adjacent to the fans were not covered and were subject to natural rainfall, which affects infiltration and runoff. To preserve the dust deposited on the ground, structures were built to cover the study areas to protect them from natural rainfall (Image 4.3). For each fan, sites were located for installation of the rainfall simulation test plot frames. Selection was determined by visual siting within the high volume dust trail and in areas with consistent slopes to obtain uniform runoff (Image 4.4). Dust volumes and deposition uniformity were expected to vary between each plot due to variability in fan operating time, as well as differences in fan mount angles and fan blade balance. Test plot frames and runoff gutters were installed prior to placement of a new flock of birds, with a roof over the plots to protect the plot surface from natural rainfall occurring during bird grow out. Roof structures were removed prior to each rainfall simulation study, and replaced following the study and prior to placement of a new flock. The only disturbance to the grass at the site was cutting following each rainfall simulation study.

Experimental Design

To test the hypotheses, an experiment was designed with the independent variables being fan type (i.e. volume of air flow when operating) and fan operation time. The dependent variable was the quantity of dust exhausted and deposited on the ground, which impacted the nutrient concentrations in the runoff. Identically sized plots were installed at each fan, roofs were constructed over the plots to prevent interference from natural rainfall, and rainfall simulations were conducted on the same day for all plots of a particular fan type. To avoid variability in nutrient content of the dust, the experiment was conducted adjacent to fans on the same broiler house at the same broiler facility.

Plot Installation

When the houses were constructed, the natural soil was graded to form raised pads. Therefore, soils adjacent to and between the houses are disturbed. Rainfall simulation plots were installed on these disturbed soils, adjacent to each ventilation fan outflow. Runoff plots of dimensions 1.0-m wide by 2-m long with 3% slope (Humphry et al., 2002) were constructed with 0.2-cm thick and 15-cm wide metal frames and were installed at each fan site, centered on the ground where the fan dust deposits after being exhausted from the house. Runoff collection gutters were installed at the bottom edge of the plots

at an angle to divert runoff to a collection basin below ground level, from which the runoff was pumped into a barrel using a peristaltic pump. The frames were designed to fit under the rainfall simulator so the areas enclosed would receive equal amounts of rainfall from the simulator (Spaeth et al., 1995).

Rainfall Simulation

Rainfall simulation studies were conducted on each plot following bird removal for five consecutive flocks over a one-year period. Simulations on sidewall ventilation fan plots were conducted over the period of April 2012 through January 2013, and on tunnel ventilation fan plots over the period April 2013 through January 2014. Structures protecting the plots from natural rainfall were removed prior to each study. A portable rainfall simulator was centered and leveled over the plot. The rainfall simulator utilized was based on the design of Miller (1987). The frame was constructed of hollow metal tubing, upon which was mounted a water supply consisting of 25-mm diameter PVC pipe. Polyethylene windscreens were attached to three sides to restrict wind impact on rainfall distribution. A water hose from the production facility's well was attached to a 25-mm diameter PVC water supply pipe. Well water was sampled during each rainfall simulation study set, and analyzed for the same parameters as the collected runoff, and the results were subtracted from the study data results. A single fixed nozzle (TeeJet^{TM} 1/2HH-SS-5OWSQ), designed for a flow rate of 210 mL s^{-1}, was installed on the water supply pipe, centered at the top of the frame and 3 m above the surface of the plot (SERA-17, 2013). A low-pressure regulator and a liquid-filled pressure gauge were used to maintain pressure at 28.3 kPa (4.1 PSI). An in-line filter was placed in the supply pipe to prevent large particles from clogging the line and nozzle.

Rainfall distribution and volume were measured prior to each simulation study using five collection pans located in each corner and the center of the plot, equidistant from each other. Pressure was maintained at 28.3 kPa (4.1 PSI) and rainfall collected for 5 minutes prior to measurement.

Rainfall simulations were conducted at an intensity of 7 cm hr^{-1}, which is equivalent to a 2-year, 24-hour storm rate, and runoff was collected for a total of 30 minutes, according to the National Phosphorus Research Project (SERA-17, 2013). Runoff was pumped from the collection basin using a peristaltic pump and delivered to a 190-L barrel.

Control Data

Experimental data were compared to results from Daniel (2008) as a control, which represent constituent nutrient concentrations in runoff collected from ungrazed pastures from November 2005 through June 2007. The ungrazed pasture site was located 4.8 km from Facility 2, and had not been fertilized or manured for the previous 10 years (1995 through 2005).

Chemical Analyses

Total runoff collected was weighed to determine volume and subsampled for chemical analyses. Subsamples were refrigerated and delivered to the University of Arkansas Water Quality Laboratory within 24 hours of collection. Well water was also sampled and prepared identically for analyses. Forty milliliters of each water sample were filtered through a 0.45 µm membrane filters immediately after collection and stored at 4^{o} C until analyzed for dissolved reactive phosphorus (DRP) by the colorimetric molybdenum-blue method of Murphy and Riley (1962). Ammonium-N (NH_4-N) and nitrate-N (NO_3-N) were analyzed colorimetrically by flow injection analysis (Lachat Instruments QuickChem 8500, Loveland, CO). One hundred twenty-five milliliters were acidified to pH <2 with sulfuric acid for sample preservation, and analyzed for total phosphorus (TP) and total nitrogen (TN) using persulfate/autoclave digestion (Patton and Kryskalla, 2003). Total P was determined by spectrophotometry (Beckman Coulter, Pasadena, CA), and TN was determined by flow injection analysis (Lachat Instruments QuickChem 8500, Loveland, CO). One hundred twenty-five milliliters were analyzed for total solids (TS) gravimetrically after over-drying at 105^{o} C for 12 hours.

Flow-Weighted Concentrations

Flow-weighted concentrations were determined by calculating the mass (i.e., the event concentration multiplied by the total volume of runoff measured in the 30-min period) for each fan from a rainfall simulation runoff event. Next, the loads for all of the plots for the runoff event were summed, and the runoff volume for all of the plots for the runoff event were summed. Finally, the sum of loads was divided by the sum of runoff volume to obtain a single flow-weighted concentration for a rainfall simulation

event for the site. This was calculated to examine the worst-case scenario if the broiler house was located adjacent to a waterway.

Statistical Analyses

Based on a randomized complete block design, a one-factor analysis of variance (ANOVA) was conducted to evaluate the effect of sampling season on the various chemical constituents for each type of fan runoff plot. Additionally, runoff volumes for each fan type were summed by test date to evaluate seasonal differences between fan types, and a one-factor ANOVA was conducted on the summed runoff volumes. Linear correlations were conducted to compare runoff nutrient concentrations at fan plots to nutrient concentrations in fan dust. All relationships are reported as statistically significant at the $p < 0.05$ level unless noted otherwise. Wolfram Mathematica (online beta version 2014, Wolfram, Champaign, IL) was used to conduct the statistical analyses.

Results and Discussion

Runoff Volumes at Fan Plots

The minimum runoff volume at the sidewall fan plots was 8.8 L at Plot 3 on 6/20/2012, and the maximum volume at the sidewall fan plots was 123 L at Plot 3 on 1/10/2013 (Figure 4.1). The minimum volume at the tunnel ventilation fan plots was 2.3 L at Plot 3 on 8/1/2013, and the maximum volume at the tunnel ventilation fan plots was 54.2 L at Plot 2 on 1/30/2014 (Figure 4.2). Observed differences in runoff volumes between plots were likely due to the effects of soil disturbance and different compaction rates during house construction. Although the minimum and maximum runoff volumes occurred on different dates, it is unclear if there was a seasonal effect due to soil moisture on runoff volume, based on the potential differences in gravimetric moisture content of the soil adjacent to the plots at the time of the rainfall simulation tests. The gravimetric moisture content of the soil adjacent to sidewall fan Plot 3 on 6/20/2012 was 16.4%, and at the same plot on 1/10/2013 the gravimetric moisture content of the adjacent soil was 7.4%. While the gravimetric moisture content of the soil adjacent to tunnel ventilation Plot 3 on 8/1/2013 was 12.6%, the gravimetric moisture content of the soil adjacent to tunnel ventilation Plot 2 on 1/30/2014 was 43%. Runoff volumes among sidewall fan plots did not differ ($p = 0.79$) over time.

Similarly, runoff volumes among tunnel ventilation fan plots did not differ (p = 0.89) over time. To compare differences between fan types over time, the volumes of runoff for sidewall fan plots were summed for each test date, and the volumes of runoff for tunnel ventilation fan plots were summed for each test date. As a result, total runoff volume, summed across plots and rainfall simulation dates, did not differ (p = 0.30) between sidewall ventilation fan runoff plots and tunnel ventilation fan runoff plots (Table 4.1).

Runoff Concentrations at Fan Plots

Runoff concentrations from fan plots were expected to vary between fans of the same type and between different fan types due to all fans operating for different times during flocks and across seasons. As previously stated, S1 and S4 operate on a timed schedule at the beginning of each flock during colder weather. Sidewall fan S3 and S4 operate on a timed schedule at the beginning of each flock during warmer weather. Once the temperature is 1.1 ^{o}C above DRT, all sidewall fans automatically operate simultaneously to maintain house temperature and humidity. Sidewall fan use dominates in cooler weather. Concentrations at sidewall fan rainfall simulation runoff plots ranged in DRP from 0.3 in August to 12.2 mg L^{-1} in April (Figure 4.3), in TP from 1.5 August to 26 mg L^{-1} in April (Figure 4.4), in NH_4-N from 3.6 in August to 59.1 mg L^{-1} January (Figure 4.5), in NO_3-N from 3.4 in August to 55.0 mg L^{-1} in June (Figure 4.6), in TN from 11.0 in August to 120.6 mg L^{-1} October (Figure 4.7), and in TS from 245.1 June to 1,617.6 mg L^{-1} in April (Figure 4.8). The month with the lowest runoff volume was June, in which runoff concentrations were expected to be greatest. However, the greatest concentrations of most parameters occurred in April, and only NO_3-N concentration was greatest in June.

As previously stated, when the in-house temperature rises to 1.6 ^{o}C above DRT, T1 automatically starts. When the in-house temperature rises to 2.2 ^{o}C above DRT, T2 automatically starts. When the in-house temperature rises to 3.1 ^{o}C above DRT, T3 automatically starts, and when the in-house temperature rises to 3.3 ^{o}C above DRT, T4 automatically starts. Tunnel fan use dominates in warmer weather. Concentrations at tunnel ventilation fan rainfall simulation runoff plots ranged in DRP from 0.2 in January to 7.9 mg L^{-1} in August (Figure 4.9), in TP from 1.0 in April to 18.2 mg L^{-1} in August (Figure 4.10), in NH_4-N from 3.9 in April to 39.6 mg L^{-1} in August (Figure 4.11), in NO_3-N from 1.1 in April to 34.2 mg L^{-1}

in August (Figure 4.12), in TN from 5.1 in April to 189.0 mg L^{-1} in August (Figure 4.13), and in TS from 9.3 April to 1,249.7 mg L^{-1} in January (Figure 4.14). The month with the lowest runoff volume was August, in which runoff concentrations were expected to be greatest. In all but one parameter, TS, the greatest concentrations did occur in August

Statistical Comparison of Runoff Concentrations at Fan Plots

Total phosphorus and WEP concentrations were at least 2.8 and 2.1 times lower ($p < 0.05$), respectively, in runoff adjacent to all side vents captured after the flock that was raised in the warm weather month (August), than those captured after the flocks that were raised in the cool weather months (October through June; Table 4.2). Total nitrogen concentrations were at least 2.4 times lower ($p < 0.05$) in runoff adjacent to side vents 2, 3 and 4 captured after the flock that was raised in the warm weather month (August) than those captured after the flocks that were raised in the cool weather months (October through June, Table 4.2). The lower concentrations of TP, WEP and TN in August were likely due to a reduction in sidewall fan use coupled with an increase in tunnel fan use. Seasonal differences (i.e. between August as the warm-weather month and all others as cool-weather months) were not observed in runoff concentrations of NH_4-N, NO_3-N, or TS from sidewall ventilation fan plots (Table 4.2).

Similar to sidewall ventilation fan plots, concentrations of TP, WEP and N in runoff adjacent to tunnel vents were at least 2.1 times greater ($p < 0.05$) in the runoff captured after the flock that was raised in the warm weather months (May through August), likely due to an increase in tunnel fan use, versus that captured after the flocks that were raised in the cool weather months (October through April; Table 4.2). Seasonal differences (i.e. between August and May as the warm-weather month and all others as cool-weather months) were not observed in runoff concentrations of NH_4-N, NO_3-N, or TS from tunnel ventilation fan plots (Table 4.2).

Runoff Concentrations at Fan Plots Compared to Runoff Concentrations to Littered Plots

The P concentrations in the runoff were also compared to data from test plots to which broiler litter was applied (Table 4.3). The runoff concentrations from the littered plots ranged from 0.66 to 33 mg L^{-1} DRP and from 3.8 to 36.7 mg L^{-1} TP (Table 4.3). By contrast, the concentrations from the fan plots

ranged from 0.2 to 12.2 mg L^{-1} DRP and 1.0 to 26.0 mg L^{-1} TP (Table 4.3). Based on this comparison, runoff concentrations from the fan plots were not greater than that observed from littered plots.

Flow-Weighted Concentrations at Fan Plots

Runoff concentration data were flow-weighted within rainfall simulation events by calculating nutrient masses measured from rainfall simulations at each fan, summing the masses across the various replicate fans, then dividing the total nutrient mass by the summed flow across the various replicate fans. This provided calculated runoff concentrations for the entire north side of house #4, and was intended to be a worse-case scenario if there were a waterway located immediately adjacent to the house.

As was previously explained, fans are operated for different purposes and at different times during a flock production cycle, which greatly affects the amount of dust exhausted by each fan. There are two modes of fan operation, DRT for temperature and minimum ventilation for air quality. Tunnel fan use is greater during warmer weather and each tunnel fan exhausts at a rate that is 2.5 times greater than a sidewall fan, thus likely resulting in substantially more dust being exhausted from the house. Additional testing would be required to determine if there are statistically significant differences in runoff concentrations between the fans. This testing was not initiated because the intent of this study was to obtain baseline data to evaluate the worse-case scenario and compare these data to that obtained at the culverts at the edge of the facility.

Flow-weighted runoff concentrations of P at sidewall ventilation fan plots and tunnel ventilation fan plots ranged in DRP from 1.8 to 8.6 mg L^{-1}, and from 0.6 to 5.3 mg L-1, respectively, and in TP from 2.8 to 16.6 mg L^{-1}, and from 2.3 to 8.7 mg L^{-1}, respectively. Flow-weighted runoff concentrations of N at sidewall ventilation fan plots and tunnel ventilation fan plots ranched in NH4-N from 8.9 to 34.8 mg L^{-1}, and from 7.3 to 25.9 mg L^{-1}, respectively, in NO3-N from 9.5 to 29.3, and from 4.1 to 19.7 mg L^{-1}, respectively, and in TN from 29.4 to 84.7 mg L^{-1}, and from 15.0 to 122.3 mg L^{-1}, respectively. Flow-weighted runoff concentrations of TS at sidewall ventilation fan plots and tunnel ventilation fan plots ranged from 584 to 1,391 mg L^{-1}, and from 166 to 1,044 mg L^{-1}, respectively.

Since tunnel ventilation fans flow at a rate 2.5 times greater than sidewall ventilation fans, runoff concentrations from plots adjacent to tunnel ventilation fans were expected to be greater than that from

plots adjacent to sidewall ventilation fans because there would likely be more dust deposition. However, visual observations of dust deposition from the different fan types indicate a much larger footprint of dust deposited by tunnel ventilation fans than by sidewall ventilation fans. Since the runoff plots were sized the same for both fan types, this resulted in rainfall simulations on plots that appeared to contain less dust volume at the tunnel ventilation plot sites than at the sidewall ventilation plot sites.

Runoff Compared to Fan Dust

Comparisons of TP and TN between ventilation fan runoff plots and fan dust yielded no correlations (Figures 4.15 and 4.16). The volume of dust emitted by each fan was not measured due to the complexities of the process.

Conclusions

This study provided baseline data for a worse-case scenario of runoff concentrations of P and N from the nutrient source at the fan outlets. Although the subject facility is not discharging directly into a waterway, the nearest waterway is the Illinois River. The Illinois River is a fresh-water basin and P is the controlling nutrient for eutrophication, so the greatest concern is contribution of P compounds. Oklahoma has set a target limit of 0.037 mg L^{-1} TP for the Illinois River when it crosses the state line from Arkansas into Oklahoma. Additionally, NH4-N discharges are a concern due to toxicity to aquatic animals, although no limits have been set by Oklahoma for this parameter. It is important to recognize that runoff concentrations from each fan plot, regardless of the season, were consistently above 1.0 mg L^{-1} TP, and 3.9 mg L^{-1} NH_4-N. If a facility is proximate to a waterway, broiler house fan dust runoff concentrations at the nutrient source could be elevated and pose a threat to water quality. Data from this study will be used to compare to data collected at other facilities, as well as to runoff data collected at the edge of this facility to determine the impact of flow distance and volume on nutrient concentrations.

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Table 4.1. Volume Comparison Between Rainfall Simulation Plots Adjacent to Sidewall and Tunnel Ventilation Fan Outlets at a Broiler Farm

Location	Month						
	April	May/June	August	October	January	P-value*	
Total Volume (L) Sidewall Fan Plots	139.2	61.7	71.7	154.7	332.3	0.79	0.30
Total Volume (L) Tunnel Fan Plots	112.7	63.6	20.9	125.6	143.2	0.89	

* P-value in first column is result for effect of season within fan type. P-value in second column is result for effect of fan type.

Table 4.2. Comparison of Rainfall Simulation Runoff Concentrations as Effected by Season at Plots Adjacent to Broiler House Fans

Sidewall Ventilation Fan Plots Average Concentration (mg L^{-1})									
Parameter†	October - June				August				P-Value*
	Fan 1	Fan 2	Fan 3	Fan 4	Fan 1	Fan 2	Fan 3	Fan 4	
TP	12.9	9.9	6.5	6.8	4.6	1.5	2.1	1.7	0.01
DRP	8.1	5.5	4.0	4.7	3.8	0.3	1.3	0.5	0.01
TN	63.2	64.5	61.7	41.9	62.4	11.0	21.0	17.3	0.01
NH_4-N	37.0	27.1	29.9	22.7	14.1	3.6	7.1	6.6	0.10
NO_3-N	30.4	23.4	25.3	10.7	46.8	3.4	9.7	5.0	0.56
TS	921	1133	797	567	603	750	495	933	0.33
Tunnel Ventilation Fan Plots Average Concentration (mg L^{-1})									
Parameter	October - April				May through August				P-Value
	Fan 1	Fan 2	Fan 3	Fan 4	Fan 1	Fan 2	Fan 3	Fan 4	
TP	2.0	1.9	3.8	4.1	5.6	4.4	13.0	12.6	0.04
DRP	0.5	0.5	1.4	3.2	4.0	3.2	5.2	6.7	0.01
TN	31.7	28.1	19.5	45.1	115.3	61.4	51.6	116.3	0.02
NH_4-N	13.4	11.3	8.8	20.5	13.4	11.3	8.8	20.5	0.32
NO_3-N	12.4	8.4	5.9	11.0	15.7	12.4	16.4	30.3	0.07
TS	532	628	550	539	359	230	570	827	0.64

† Parameters tested included total phosphorus (TP), dissolved reactive phosphorus (DRP), total nitrogen (TN), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), and total solids (TS).

* P-value results for effect of season

Table 4.3. Phosphorus Runoff from Plots Treated with Broiler Litter Compared to Ventilation Fan Plots

Reference	Location	Forage Type	kg ha^{-1}	mg L^{-1}	
			P Applied	DRP	TP
DeLaune et al. (2004)	Washington County, AR	Fescue	35.4	8.8	9.2
			71.1	16.6	17.2
			111	27.7	29.4
			142	33	34.9
Edwards and Daniel (1993)	Fayetteville, AR	Fescue	54	12.7	14.2
			108	30	36.7
Harmel et al. (2004)	Blackland Prairie, TX	Bermuda	124	0.66	
		Kleingrass	257	1.29	
Kleinman et al. (2001)	New York	Fescue	100	11.5	13.6
Sistani et al. (2010)	Crossville, AL	Fescue	234	2.35	3.8
Smith et al. (2004)	Washington County, AR	Fescue	105	5.6	8.2
Sidewall and Tunnel Fan Plots	Washington County, AR	Fescue and Bermuda		0.2 - 12.2	1.0 - 26.0

Table 4.4. Flow-Weighted Concentrations from Runoff Plots Adjacent to Sidewall Ventilation Fans and Tunnel Ventilation Fans at a Broiler House

Fan Type	Event Date	mg L^{-1}					
		DRP†	TP	NH_4-N	NO_3-N	TN	TS
Sidewall	4/18/2012	8.6	16.6	32.7	29.3	84.7	1,391
	6/20/2012	4.1	4.9	19.2	28.3	47.6	598
	8/23/2012	1.8	2.8	8.9	20.6	33.2	703
	10/31/2012	3.9	6.4	28.0	20.2	59.4	584
	1/10/2013	6.2	9.7	34.8	9.5	29.4	849
Tunnel	04/11/13	1.5	2.3	7.3	4.1	15.0	166
	05/30/13	4.4	6.0	10.7	19.7	55.8	573
	08/01/13	5.3	8.7	25.9	17.1	122.3	432
	10/22/13	1.6	3.6	22.5	10.6	48.3	566
	01/03/14	0.6	2.6	9.8	10.6	26.9	1,044
Control*		0.1	0.1		0.1	0.6	43

† Parameters include dissolved reactive phosphorus (DRP), total phosphorus (TP), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total nitrogen (TN), and total solids (TS)

*Ungrazed pastures that were not fertilized or manured for 10 years (Daniel 2008).

Figure 4.1. Rainfall Simulation Runoff Volumes at Sidewall Fan Plots

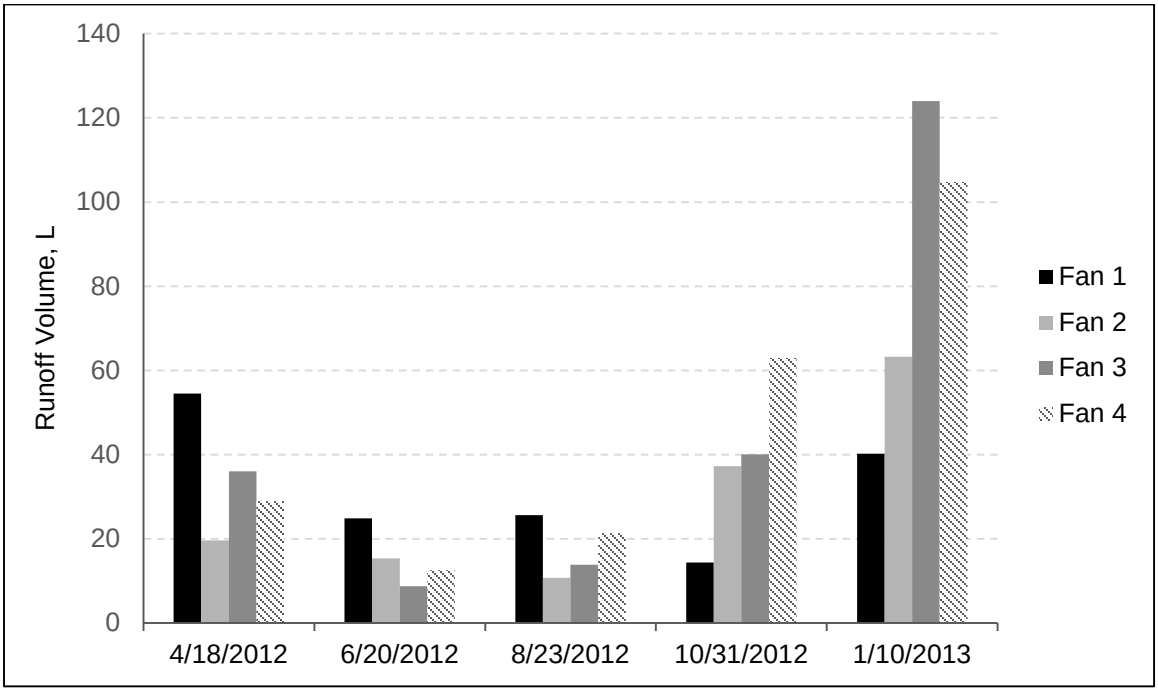

Figure 4.2. Rainfall Simulation Runoff Volumes at Tunnel Fan Plots

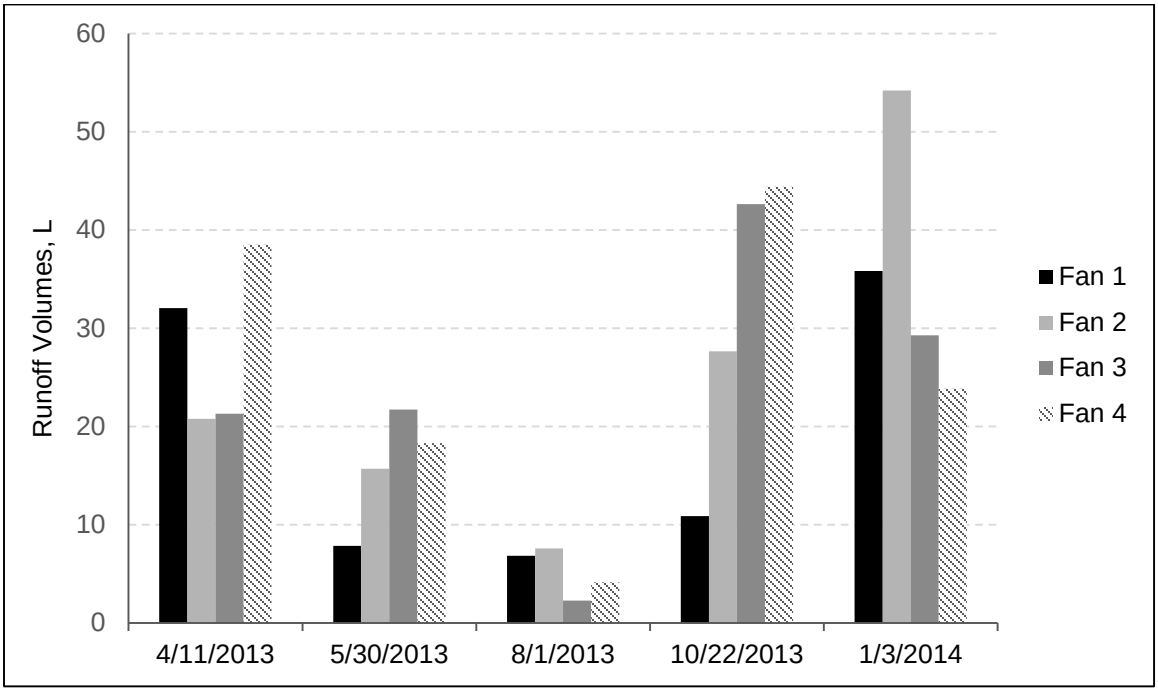

Figure 4.3. Concentrations of Dissolved Reactive Phosphorus in Runoff from Plots Adjacent to Sidewall Ventilation Fans as a Function of Season

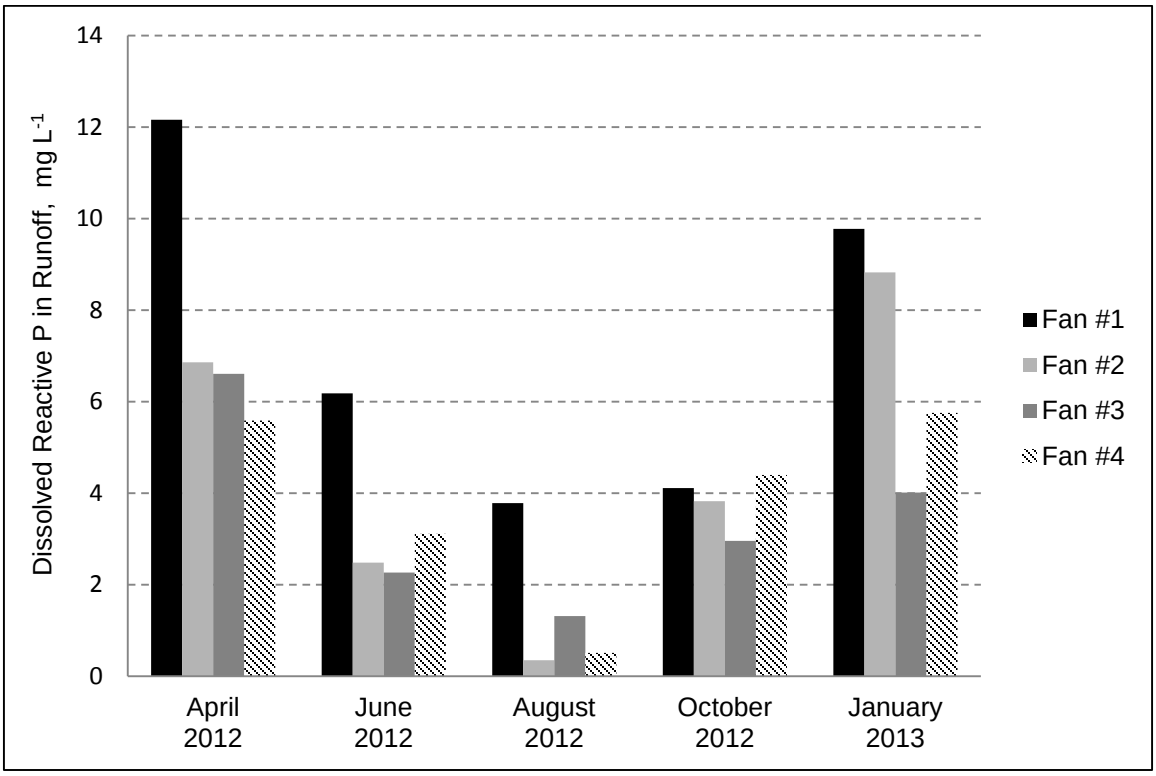

Figure 4.4. Concentrations of Total Phosphorus in Runoff from Plots Adjacent to Sidewall Ventilation Fans as a Function of Season

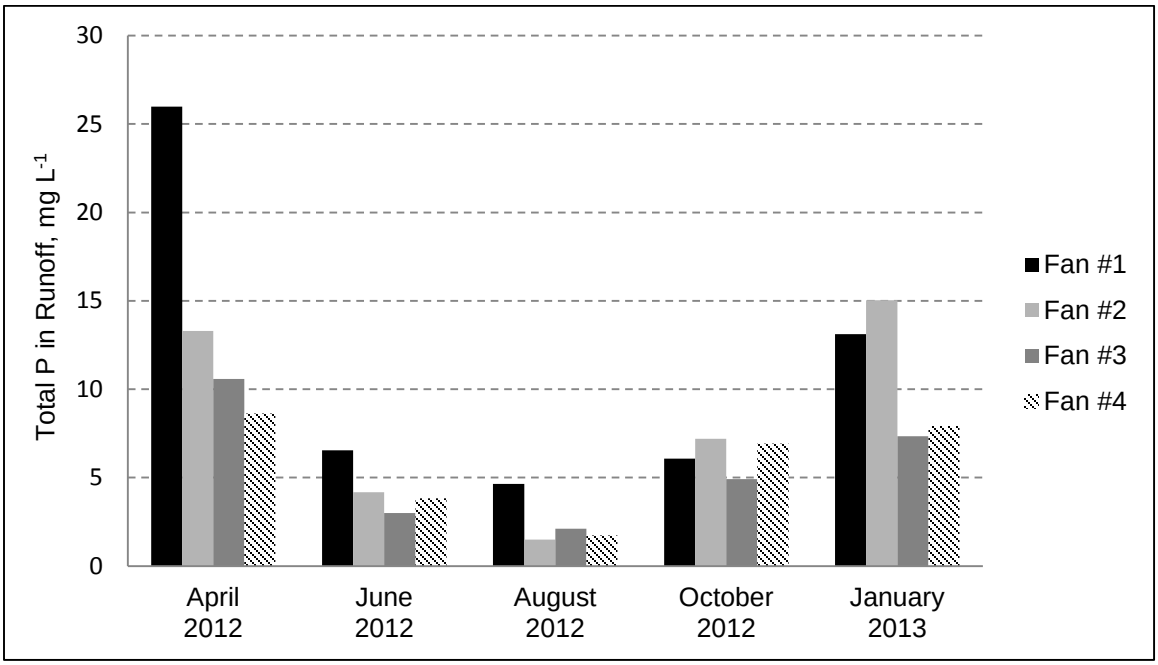

Figure 4.5. Concentrations of Ammonium-N in Runoff from Plots Adjacent to Sidewall Ventilation Fans as a Function of Season

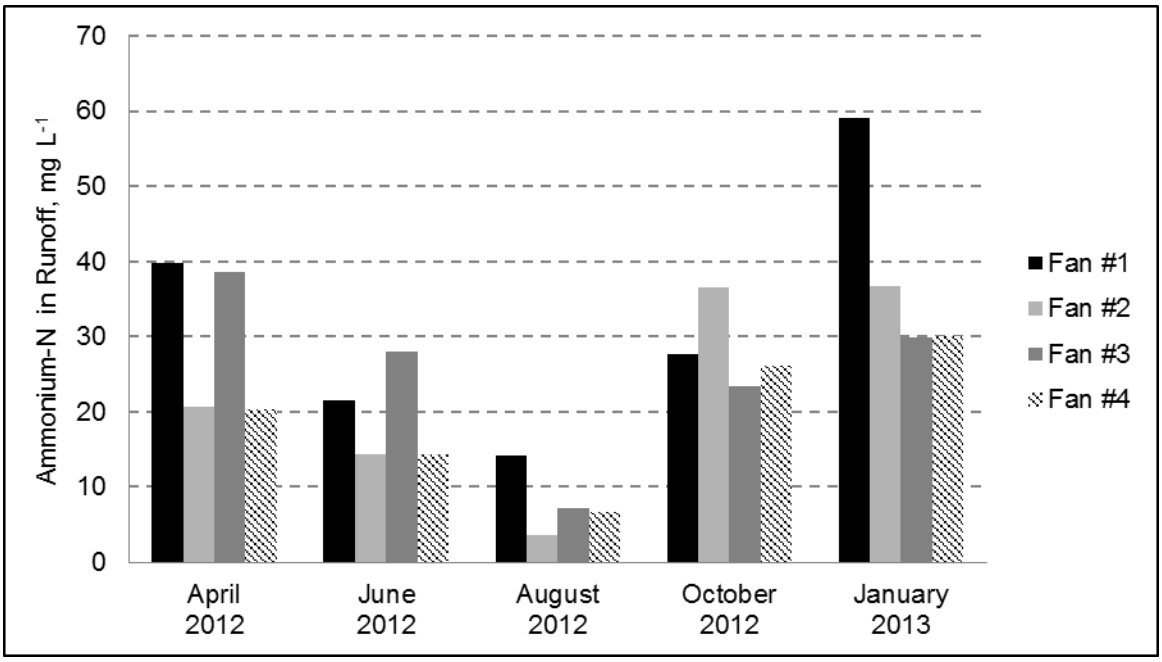

Figure 4.6. Concentrations of Nitrate-N in Runoff from Plots Adjacent to Sidewall Ventilation Fans as a Function of Season

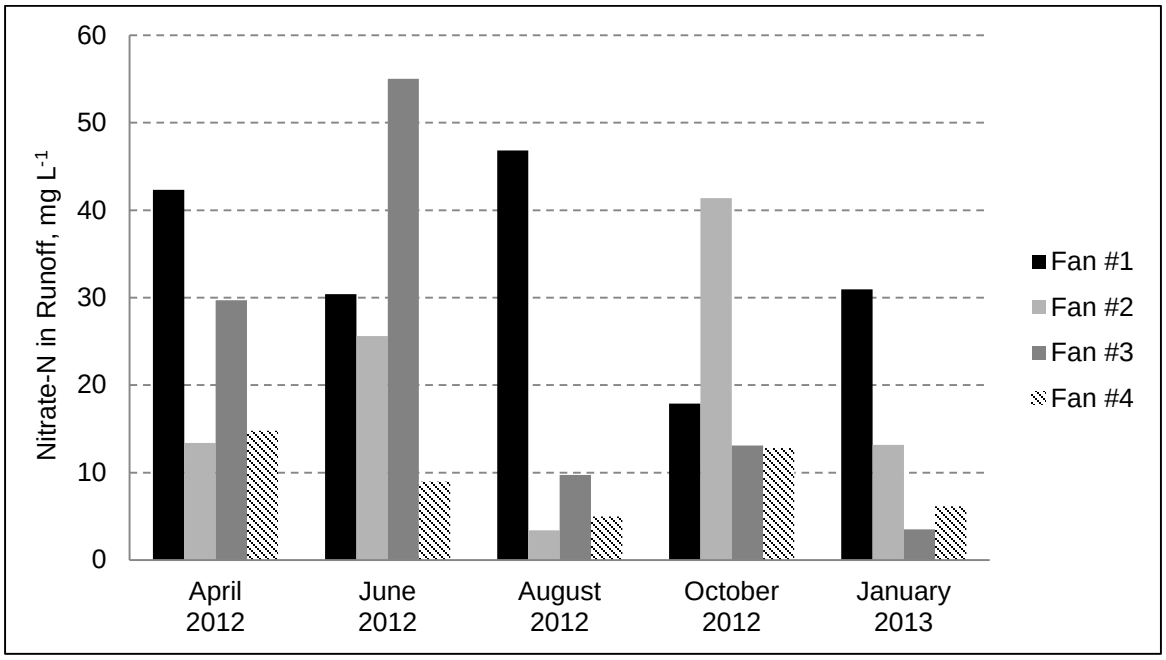

Figure 4.7. Concentrations of Total Nitrogen in Runoff from Plots Adjacent to Sidewall Ventilation Fans as a Function of Season

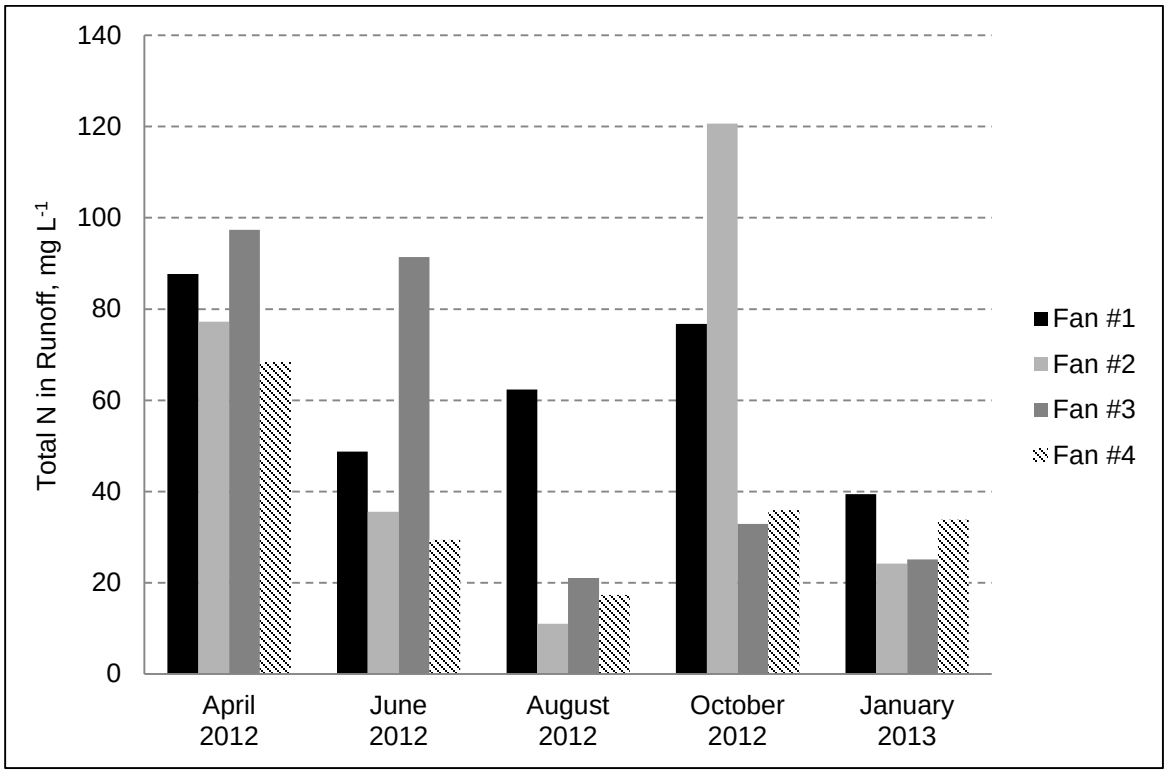

Figure 4.8. Concentrations of Total Solids in Runoff from Plots Adjacent to Sidewall Ventilation Fans as a Function of Season

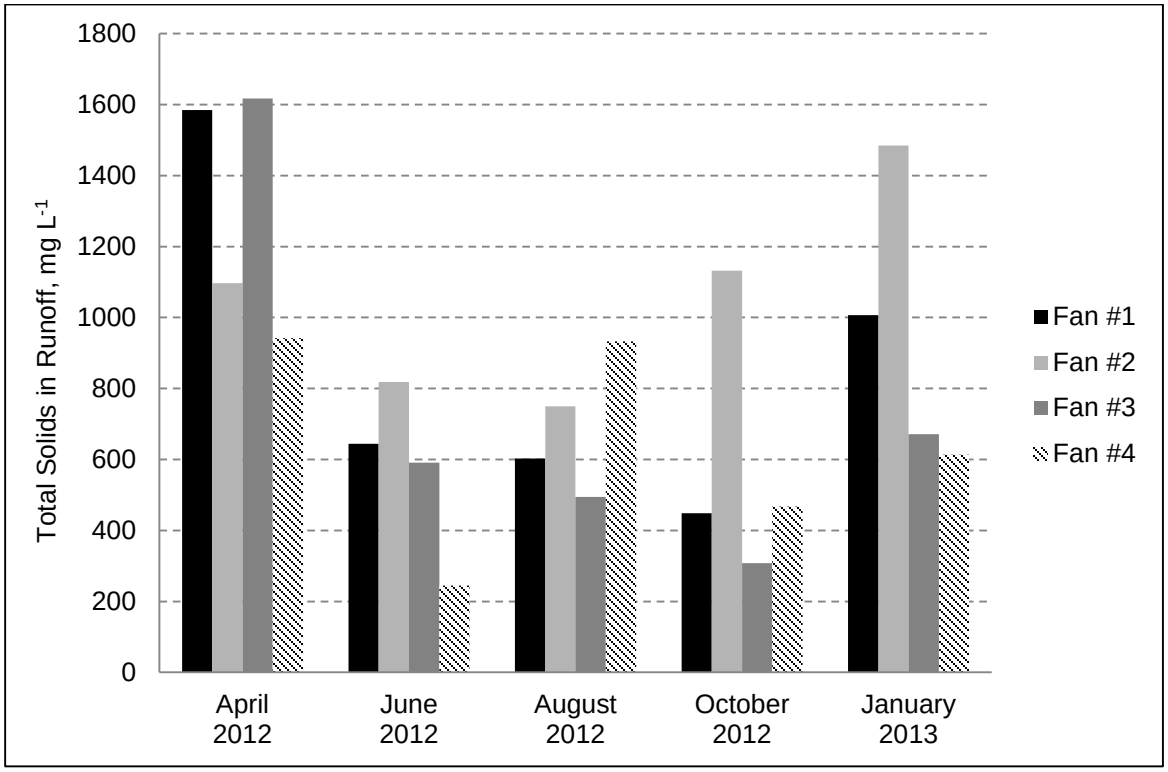

Figure 4.9. Concentrations of Dissolved Reactive Phosphorus in Runoff from Plots Adjacent to Tunnel Ventilation Fans as a Function of Season

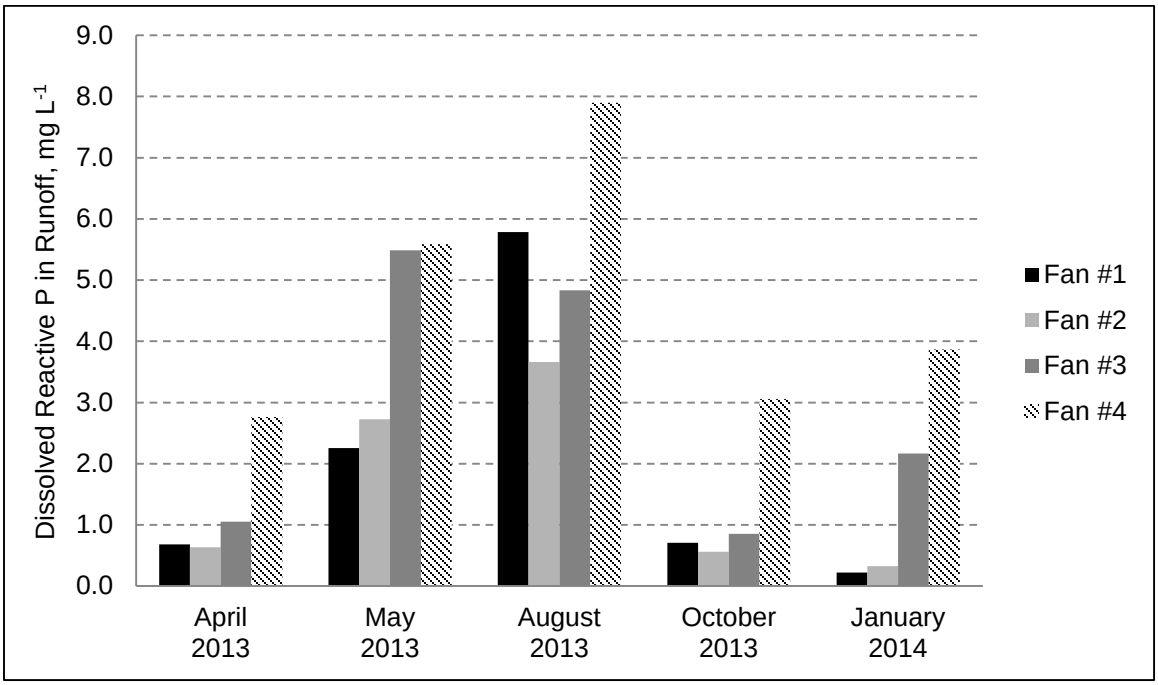

Figure 4.10. Concentrations of Total Phosphorus in Runoff from Plots Adjacent to Tunnel Ventilation Fans as a Function of Season

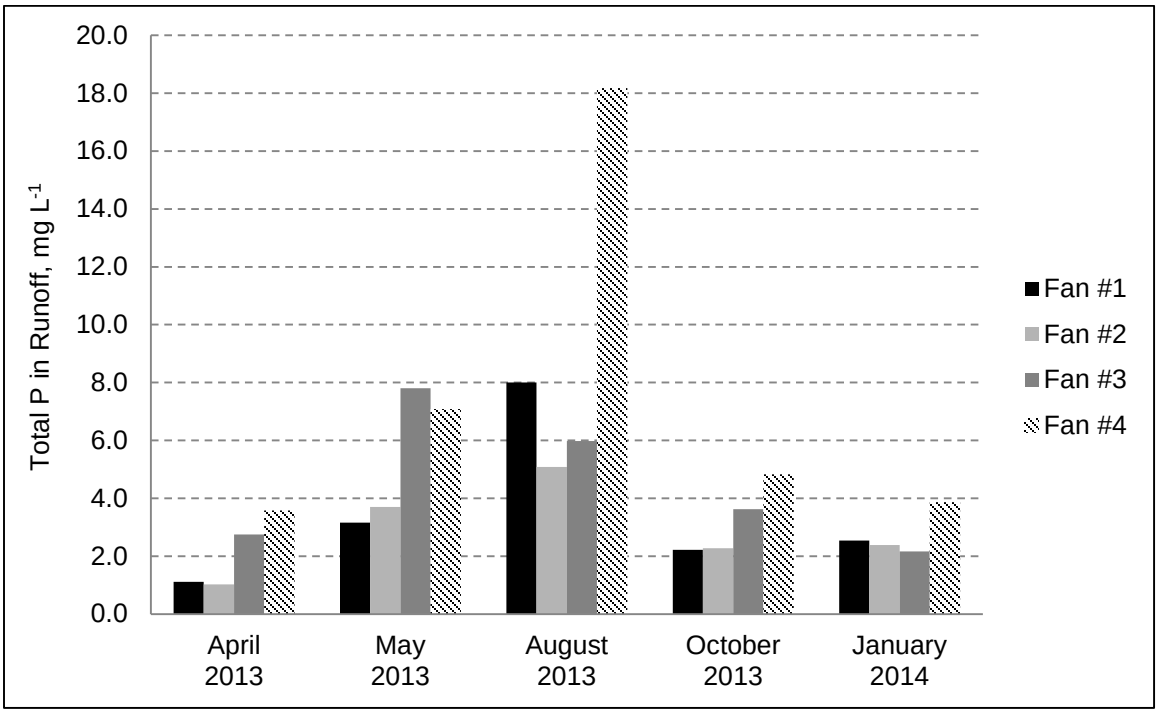

Figure 4.11. Concentrations of Ammonium-N in Runoff from Plots Adjacent to Tunnel Ventilation Fans as a Function of Season

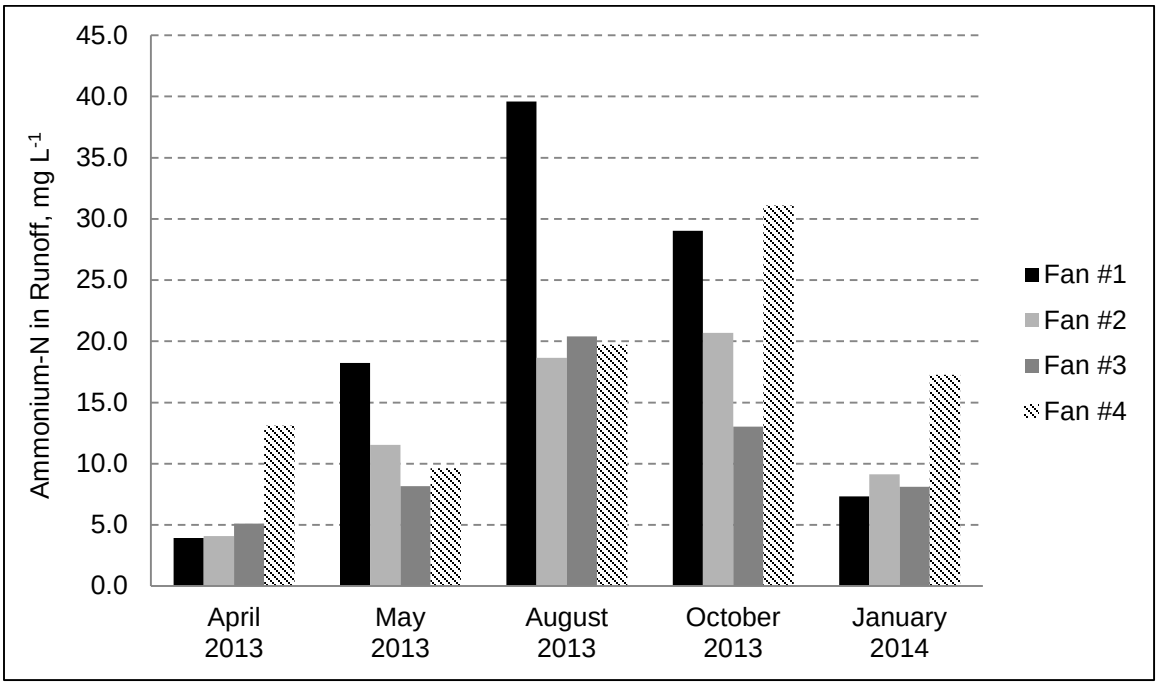

Figure 4.12. Concentrations of Nitrate-N in Runoff from Plots Adjacent to Tunnel Ventilation Fans as a Function of Season

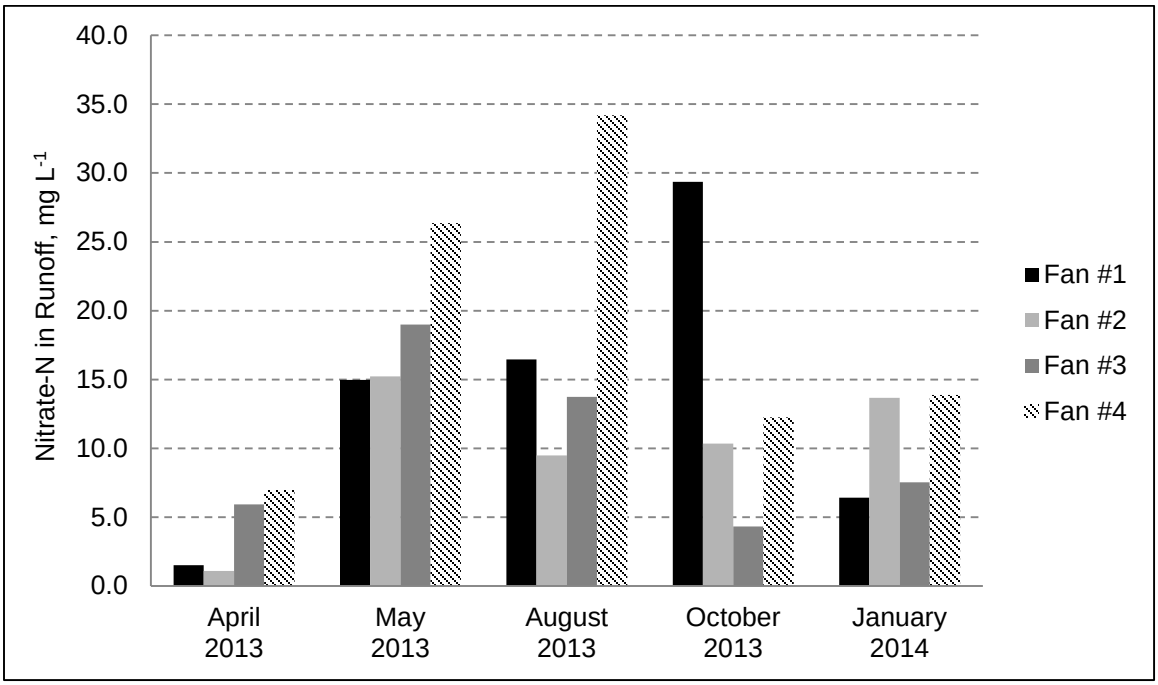

Figure 4.13. Concentrations of Total Nitrogen in Runoff from Plots Adjacent to Tunnel Ventilation Fans as a Function of Season

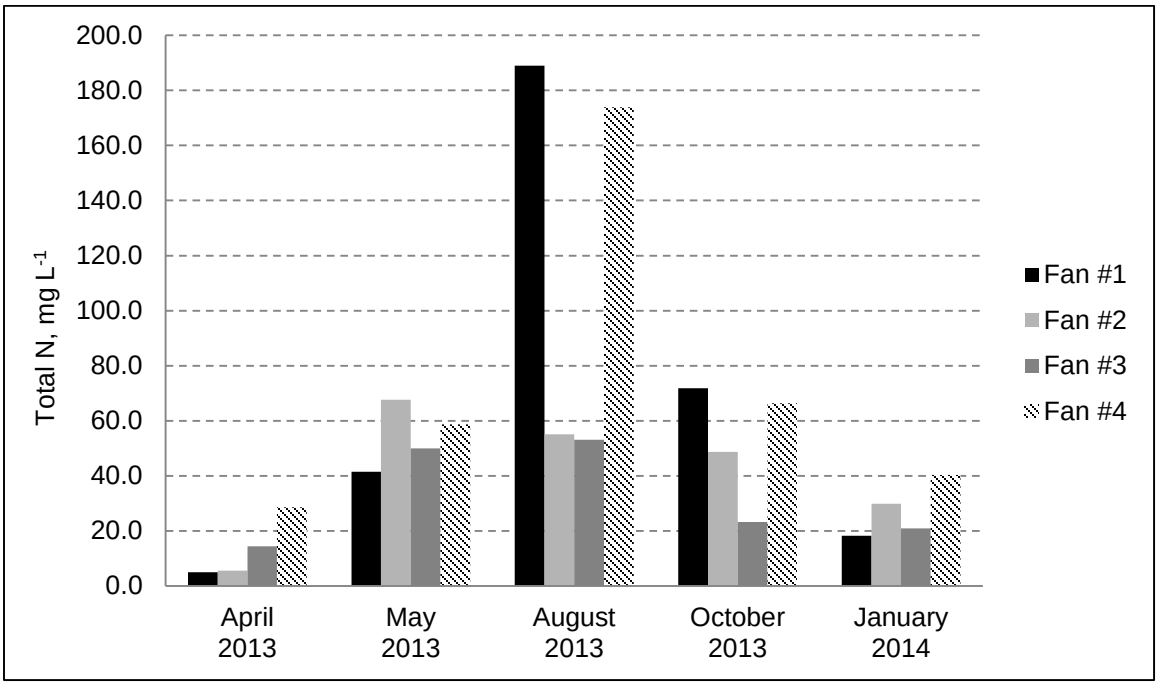

Figure 4.14. Concentrations of Total Solids in Runoff from Plots Adjacent to Tunnel Ventilation Fans as a Function of Season

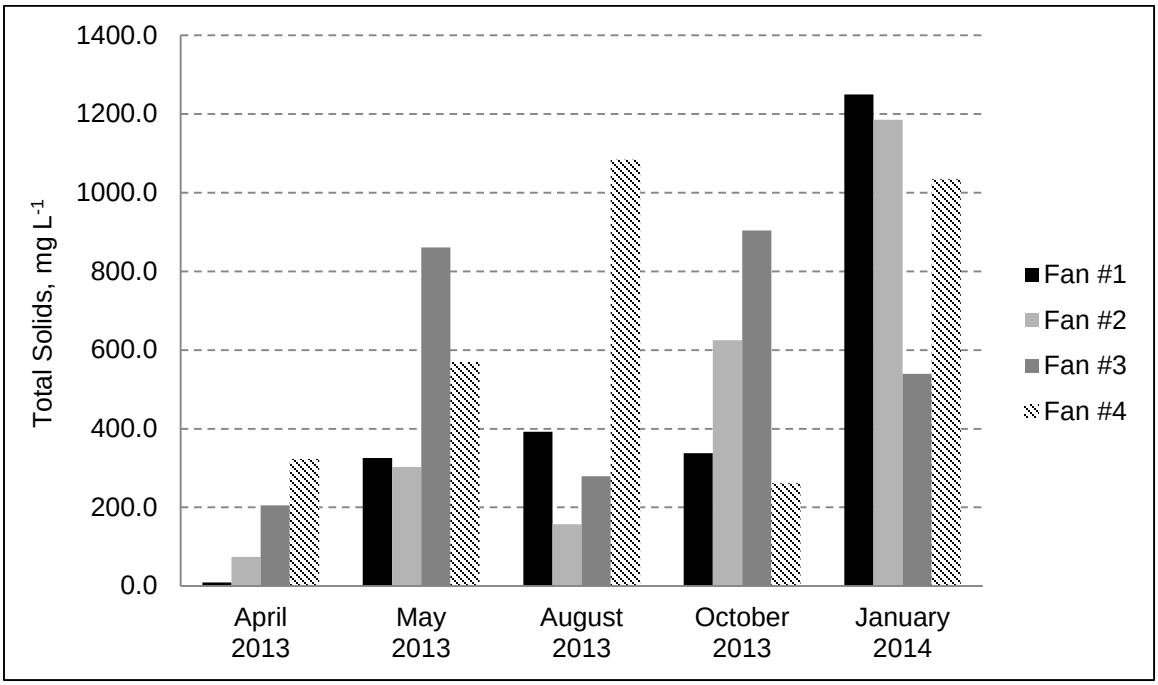

Figure 4.15. Comparison of Total Phosphorus from Sidewall Fans Flow-Weighted Concentrations and Average Dust Concentrations

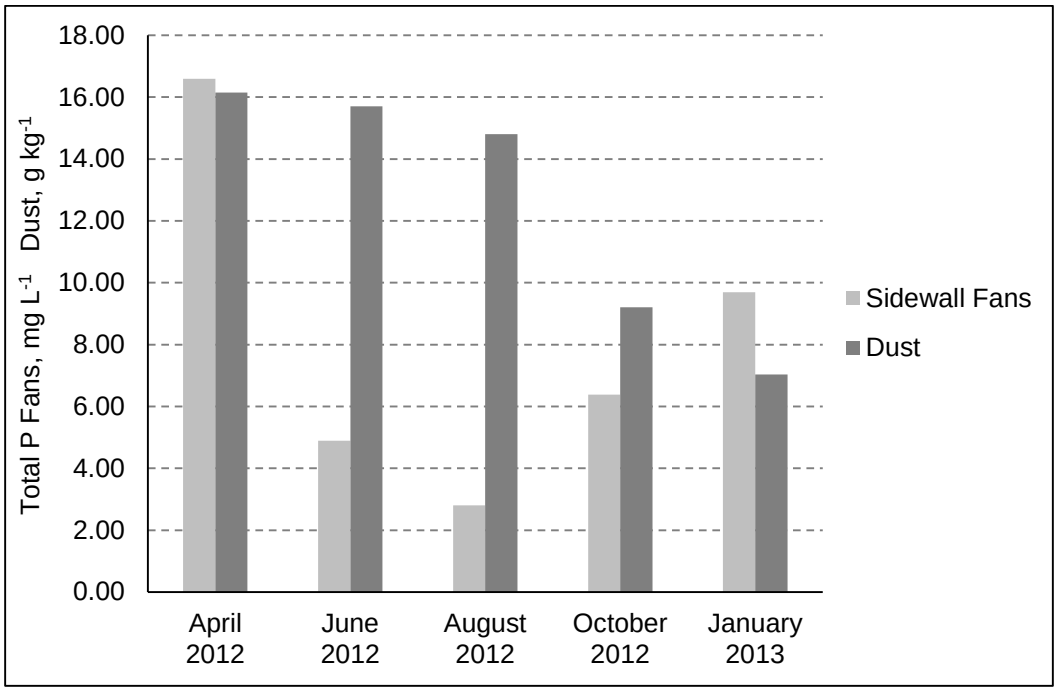

Figure 4.16. Comparison of Total Nitrogen from Sidewall Fans Flow-Weighted Concentrations and Average Dust Concentrations

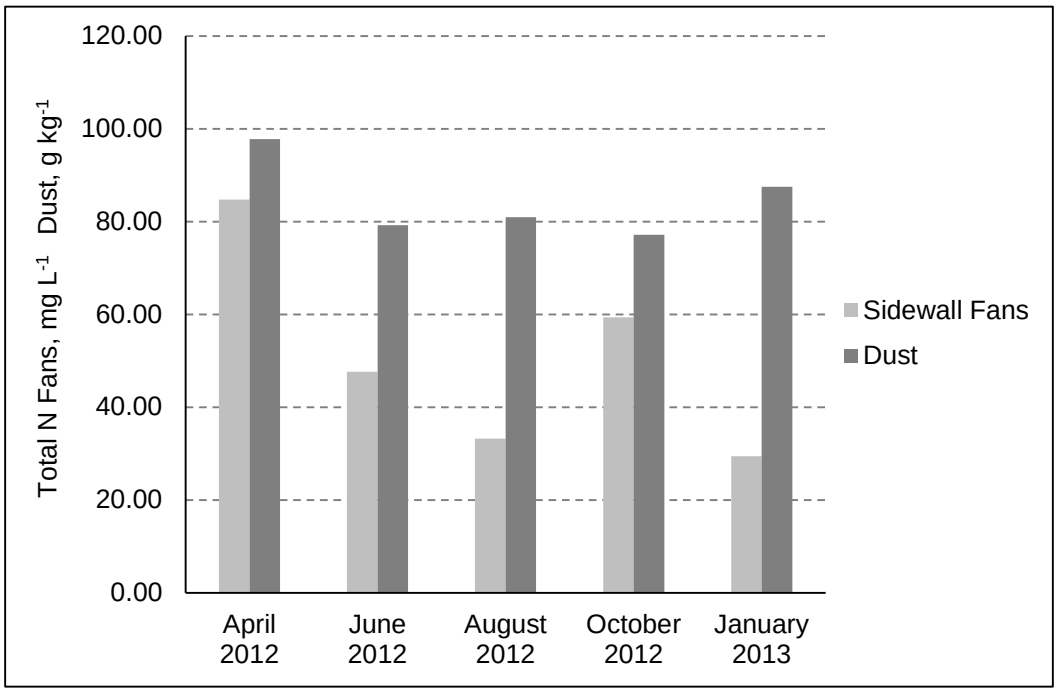

Image 4.1. Location of Sidewall Plots and Flow Direction at Facility 2

Adapted from image from Google Earth, 2012

Image 4.2. Location of Tunnel Plots and Flow Direction at Facility 2

Adapted from image from Google Earth, 2012

Image 4.3. Structures to Protect Ground from Natural Rainfall at Facility 2

Herron, 2012

Image 4.4. Rainfall Simulation Plot Borders and Gutter at Facility 2

Herron, 2012

CHAPTER 5

STORMWATER RUNOFF VOLUMES AND NUTRIENT LOADING FROM A BROILER PRODUCTION FACILITY

STORMWATER RUNOFF VOLUMES AND NUTRIENT LOADING FROM A BROILER PRODUCTION FACILITY

Abstract

Discharge of nutrients from broiler production areas is not currently regulated. However, nutrient discharge in runoff from broiler production areas is of increasing concern to regulatory agencies. To quantify production area losses, runoff was automatically sampled at two culverts draining the land between four broiler houses. Phosphorus (P), nitrogen (N), and sediment concentrations were measured in runoff from storm events between April 2012 and August 2013. The entire area between houses 2 and 3 (culvert C1A) is a grassed swale with no access road, while the grassed drainage swale between houses 3 and 4 (culvert C2A) contains an access road that reduced the permeable surface area. As a result, there was 19% more runoff events at C2A than at C1A. There were 117 measurable rainfall events at the site. Of these, 27 produced measureable runoff volumes at C2A, while only 22 produced measureable runoff volumes at C1A. Concentrations of total nitrogen (TN) were greater at C2A than at C1A in all but four runoff events. Concentrations of total phosphorus (TP) at C2A were greater than at C1A in all but one event. This was likely a result of increased runoff volumes at C2A, which mobilized and transported more nutrients and sediment. Average concentrations at C2A of dissolved reactive phosphorus (DRP), TP and total solids (TS) were twice that at C1A, while nitrate nitrogen (NO_3-N) and TN were 1.5 times that at C1A. These differences reflect the fact that as the area of impermeable surfaces increases, the concentration of nutrients and sediment in runoff also increases due to less infiltration of runoff-water and nutrients into the soil and to increased transport capacity of the runoff. Total annual P loads were numerically greater for both culverts (7.9 kg ha^{-1} yr^{-1} at C2A and 1.5 kg ha^{-1} yr^{-1} at C1A) than typical losses from northwest Arkansas pastures receiving broiler litter at a rate of 1.3 kg ha^{-1} yr^{-1} (1.5 ton litter $acre^{-1}$ yr^{-1}). As stormwater runoff from broiler production facilities has the potential to be enriched in P and N, conservation measures are needed to minimize such losses and protect local surface waters.

Introduction

Stormwater discharge of contaminants is a growing concern across the country. The U.S. Environmental Protection Agency (EPA) currently requires permits under the Clean Water Act (CWA) to control discharges from industrial facilities and construction sites (U.S. EPA, 1972). However, the CWA provides a stormwater permit exemption for agricultural fields, which has been used to exempt land around confined animal production areas as well. Recently, EPA challenged the portion of the exemption being claimed for confined animal production areas, arguing that confined animal production areas are industrial sites and should, therefore, be required to comply with stormwater discharge permits. This concern arose from the 2000 National Water Quality Inventory of each state, which reported that agricultural nonpoint source (NPS) is the primary source of contaminants impacting rivers and lakes (U.S. EPA, 2000). The EPA provides funds for implementation of water quality best management practices (BMPs) through the CWA 319(h) program (U.S. EPA 1984), including $30 million of cost-shared conservation programs in Arkansas between 2011 and 2015 (USDA NRCS, 2011). In spite of funding and education programs, water quality impairments across the country remain a primary concern (U.S. EPA, 2011).

The EPA has been using the CWA as the legal basis for fining broiler producers for stormwater discharges from their production areas. The CWA does not specifically state that production areas are exempt from the law. However, a federal judge recently ruled against EPA in a lawsuit filed by a broiler producer in the Chesapeake Bay watershed, arguing that historical interpretation of the law supports the exemption (Alt et al. v U.S. EPA et al., 2013). This ruling has not halted EPA efforts to pursue enforcement under the Confined Animal Feeding Operations (CAFO) rule (U.S. EPA, 2012) of the CWA and to conduct inspections and sampling on facilities in the Chesapeake Bay watershed and in nutrient surplus watersheds along the state line between Arkansas and Oklahoma (Sieger, 2013).

Broiler production facilities are designed so each production house is built on a raised pad, with a depression between houses to direct rainfall runoff away from the houses. Runoff from properly designed facilities flows through grassed swales to increase infiltration and nutrient uptake, and reduce erosion. Excess rainfall that does not infiltrate creates runoff that transports nutrients from broiler fan dust and

spilled litter. The University of Arkansas Savoy broiler production facility (Facility 2) is designed with culverts to transport the nutrient-enriched runoff under an access road and into a pasture.

The primary objective of this study was to characterize and compare natural rainfall runoff and runoff water quality from land around two houses at Facility 2, located in Washington County, AR. It was hypothesized that the broiler house dust and tracked litter have the potential to enrich runoff, as compared to runoff from fields where there are no depositions of dust or tracked litter, from the production area with P and N. It was further hypothesized that runoff volumes and nutrient concentrations are greater from drainage areas between broiler production houses that contain a road and grassed swale, than from drainage areas between broiler production houses that contain only a grassed swale. As stated in Chapter 4, runoff P concentrations from plots adjacent to broiler fan outflows were comparable to those from pastures to which large quantities of P (105 kg ha^{-1}) in broiler litter had been applied (>6 Mg ha^{-1} or >3 ton $acre^{-1}$). However, nutrients in runoff from locations near fans are expected to be diluted when combined with flow from the entire drainage area between the houses.

Materials and Methods

Experimental Design

To test the above hypotheses, this experiment was designed with the independent variables being the nutrient transport path and its associated landuse (one large grassed swale versus one grassed swale with a gravel road between). The dependent variables were the flow volume and nutrient concentrations in the runoff. Testing occurred at one facility to ensure similar nutrient sources contributing to each flow path. For each drainage swale, runoff consisted of that from the roofs of one side of each of two broiler houses, and the drainage swale between the houses. All runoff flowed one direction and exited through a culvert for the particular drainage area. It was assumed the initial volumes of rainfall runoff entering each drainage area were similar. Although runoff and nutrient concentrations were measured periodically over time, sampling events were treated as discrete since rainfall runoff volume and timing, and nutrient contributions were variable.

Site Description

This study was conducted at the University of Arkansas Savoy broiler facility, located in Washington County, AR. The entire area between houses 2 and 3 (culvert C1A) is a grassed swale with no access road. The area between houses 3 and 4 (culvert C2A) contains an access road between two grassed drainage swales, resulting in a smaller permeable surface area than the area between houses 2 and 3. Image 5.1 depicts the arrangement of the four broiler houses and the two culverts relative to each other. The soils in the drainage swales were disturbed during facility construction and the surface soil textures of both swales were inconsistent. Surface soils were hand textured and consisted of silt loam, gravelly silt loam, very gravelly silt loam, silty clay loam, and silty clay. The native soil of both drainage swales is Nixa very gravelly silt loam (loamy-skeletal, siliceous, active, mesic Glossic Fragiudult).

Equipment

Automatic samplers (Teledyne Isco Model 6712 or 2700, Lincoln, NE) were installed at two 45.7-cm diameter culverts, to collect natural rainfall runoff. The culverts drain runoff from between the north side of house 2 and the south side of house 3 (C1A), and from between the north side of house 3 and the south side of house 4 (C2A). There is a gravel road between houses 3 and 4, which decreases the permeable surface area by 10%, resulting in increased runoff.

The samplers were placed inside plastic sheds mounted on wooden platforms. Power was supplied to the samplers by 12-volt batteries, which were charged from solar panels. Conduit was installed from the sides of the sheds to the culverts to house the transducers, used to enable the samplers, and suction hoses. The transducers and suction hose strainers were attached with metal perforated straps to the inside bottom of the culverts to intercept flow (Image 5.2).

The samplers were programmed to enable when 1.27 cm of water was covering the transducer in the culvert. Sample volumes of 100 mL were collected every 5,678 L and composited in one 10-L container. A continuously recording rain gauge was installed adjacent to C2A to measure rainfall amount for each event. A modem was attached to the sampler at C2A to send notification when the sampler enabled. Runoff was collected between April 2012 and August 2013.

Chemical Analyses

Runoff collected by the automatic samplers was subsampled and 1 L was retained from each sampler for analyses. Subsamples were refrigerated and delivered to the University of Arkansas Water Quality Laboratory within 24 hours of collection. Tap water was also sampled and prepared identically for analyses. Forty milliliters were filtered through 0.45-um membrane filters immediately after collection and stored at 4 ^{o}C until analyzed for DRP by the colorimetric molybdenum-blue method of Murphy and Riley (1962). Ammonium-N and NO_3-N were analyzed colorimetrically by flow injection analysis (Lachat Instruments QuickChem 8500, Loveland, CO). One hundred twenty-five milliliters were acidified to a pH of <2 with concentrated sulfuric acid for sample preservation, and analyzed for TP and TN using persulfate/autoclave digestion (Patton and Kryskalla, 2003). Total P was determined by spectrophotometry (Beckman Coulter, Pasadena, CA), and TN was determined by flow injection analysis (Lachat Instruments QuickChem 8500, Loveland, CO). One hundred twenty-five milliliters were analyzed for TS gravimetrically after oven-drying at 105 ^{o}C for 12 hours.

Load Calculations

Loads are often considered to be more important than concentrations when evaluating nutrient contributions to waterways. The greater the load, the greater the impact to eutrophication. For comparison to discharges to waterways and to data collected at other sites, masses for each runoff event were determined by multiplying total event flow at the culvert by the measured concentrations of DRP, TP, NH_4-N, NO_3-N, TN, and TS.

Statistical Analyses

A one-factor analysis of variance (ANOVA) was conducted to evaluate the effect of culvert on concentrations and masses of various chemical constituents and runoff volume differences between the two culverts. The sample groups were comprised of event nutrient concentrations, event masses, or event volumes for each culvert. All relationships are reported as statistically significant at the $p < 0.05$ level unless noted otherwise. Wolfram Mathematica (online beta version 2014, Wolfram, Champaign, IL) was used to conduct the statistical analyses.

Results and Discussion

Runoff and P and N Transport

During the sample collection period, between April 2012 and August 2013, there were 117 rainfall events, of which 22 resulted in runoff samples for C1A and 27 for C2A (Figure 5.1). Although total runoff volume at C2A was 1.7 times greater than at C1A, averaged over events, runoff volume did not differ ($p > 0.05$) between culverts on a per event basis. Runoff varied based on antecedent soil moisture and rainfall volume, with a minimum of 0.42 cm required to produce runoff sufficient to trigger the autosamplers. The lowest rainfall period was during the month of May 2012, which generated no runoff samples. The largest rainfall period was during the month of April 2013, which generated four runoff sampling events.

Runoff concentration data were flow-weighted for the sampling period by calculating nutrient masses measured for each runoff event, summing the masses across all events, then dividing the total nutrient mass by the summed flow across sampling period. Average flow-weighted concentrations at C2A of DRP (1.5 mg L^{-1}), TP (2.1 mg L^{-1}), NO_3-N (2.8 mg L^{-1}), and TS (200 mg L^{-1}) were at least twice that at C1A (Table 6.1). Average flow-weighted concentrations at C2A of TN (6.8 mg L^{-1}) were 1.5 times that at C1A (Table 6.1). Concentrations of total nitrogen (TN) were greater at C2A than at C1A in all but four runoff events. Concentrations of total phosphorus (TP) at C2A were greater than at C1A in all but one event. The greater concentrations at C2A versus C1A were likely a result of increased runoff volumes at C2A, which mobilized and transported more nutrients and sediment. Thus, as impermeable surface area increased, runoff volume and nutrient and sediment concentrations increased due to reduced infiltration. In fact, the total volume collected for the study period at C2A (2,273,616 L) was almost twice as much as that at C1A (1,274,019 L). In addition, total annual P loads were numerically greater for both culverts (7.9 kg ha^{-1} yr^{-1} at C2A and 1.5 kg ha^{-1} yr^{-1} at C1A) than typical loads from northwest Arkansas pastures receiving 1.3 kg litter ha^{-1} yr^{-1} (1.5 ton $acre^{-1}$ yr^{-1}) (DeLaune et al., 2004).

Concentrations of P (Figure 5.2) and N (Figure 5.3) in runoff varied seasonally as a result of litter management (house cleanout), bird removal, and climate variations (ventilation fan use). Litter was removed from all houses in October 2012. This resulted in spillage and tracking of litter on the ground

outside the doors on the east side of the houses. The roads and driveways to the doors were constructed of dirt and gravel, making it difficult to scrape and remove spilled and tracked litter, which was reflected in the spike in the concentrations of P and N forms at each culvert for the runoff event directly following litter removal.

Concentrations of P and N in runoff were elevated during periods of warm weather, as compared to periods of cool weather, due to the increase in ventilation of the houses and, therefore, an increase in dust emitted by the fans. However, during the warmest weather, the house temperatures rose above desired room temperature, likely causing an increase in microorganism activity in the litter and increased volatilization of NH_3. The NH_3 subsequently was exhausted through the fans as a gas and not bound to particulate matter.

When several runoff events occurred close together (i.e. August 2012 and April 2013), there appeared to be an increase in the variability of nutrient concentrations in runoff (Figure 5.2 and 5.3). This was likely the result of nutrient flushing that was dependent on the amount, duration, and intensity of each rainfall.

Runoff Nutrient Masses

Nutrient masses discharged from each culvert for the sampling period were compared for differences associated with landuse. Total masses of DRP, TP, and TS at C2A were at least 3.9 times greater ($p < 0.05$) than those at C1A (Table 5.2). Though not significantly, total mass of NH_4-N was 1.9 times numerically greater at C2A than at C1A (Table 5.2). Total mass of NO_3-N was 3.6 times greater ($p < 0.05$) at C2A than at C1A (Table 5.2). TN was 2.7 times greater at C2A than at C1A (Table 5.2). The road between houses 3 and 4 reduced the permeable surface area by 10%, resulting in greater quantities of nutrients being transported to C2A than to C1A.

Culvert and Fan Plot Runoff Comparison

Nutrient concentrations from the rainfall simulation plots adjacent to the fans (Chapter 4) were compared to those at the culverts (Table 5.1). The DRP and TP concentrations at the fans were at least 5.6 and 2.5 times numerically greater than those at C1A and C2A, respectively. The NH_4-N, NO_3-N, and

TN concentrations at the fans were at least 11.7 and 6.1 times numerically greater than those at C1A and C2A, respectively. The TS concentrations at the fans were 7.6 and 3.5 times numerically greater than those at C1A and C2A, respectively. The concentrations at the culverts were greatly reduced due to dilution as a result of runoff from the roofs and the entire land area between the houses.

Conclusions

Runoff volumes at the culverts were two-fold greater at the culvert draining the area with the road, which created a larger impervious surface area. Alternatively, the drainage area with no road and good vegetative cover allowed for a significant volume of water, along with nutrients, to infiltrate into the soil. At facilities with drainage areas dominated by less permeable surfaces, the risk of nutrient enrichment of runoff is greater than those dominated by permeable soil and grass cover.

The culverts where runoff was sampled were at the edge of the facility. Concentrations of nutrients in runoff at the culverts were notably lower than concentrations of nutrients in runoff from fan plots receiving simulated rainfall. However, if a broiler production facility is located adjacent to a waterway, there is risk of nutrient enrichment of the waterway from runoff from the land around the production area if there are not sufficient flow and/or nutrient reduction measures in place.

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Table 5.1. Site Comparison: Minimum, Maximum, and Average Flow-Weighted Nutrient Concentrations (mg L^{-1}) and Volumes (L) at Culverts over Sampling Period, and Average Flow-Weighted Nutrient Concentrations at Fan Plots

Water Quality Parameter*	P-value†	Culvert C1A			Culvert C2A			Fan Plots		
		Min	Max	Average	Min	Max	Average	Min	Max	Average
DRP	<0.001	0.2	2.8	0.7	0.8	4.6	1.5	0.6	8.6	3.8
TP	<0.001	0.3	3.3	0.9	1.0	6.5	2.1	2.3	16.6	6.4
NH_4-N	0.825	0.3	5.0	1.7	0.5	7.2	1.8	7.3	34.8	20
NO_3-N	0.008	0.4	4.2	1.4	0.8	7.6	2.8	4.1	29.3	17
TN	0.005	1.7	9.3	4.4	2.8	14.9	6.8	15	122.3	52.3
TS	<0.001	56	151	91	93	518	200	166	1391	691
Volume	0.161	6,382	134,094	57,910	4,240	302,362	84,208			

*Parameters include dissolved reactive phosphorus (DRP), total phosphorus (TP), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), total nitrogen (TN), and total solids (TS).

† P-value is comparison of the average concentration or runoff volume across all sampling dates for Culverts C1A and C2A

Table 5.2 Nutrient Masses at Culverts C1A and C2A Over the 17-Month Monitoring Period

Parameter*	P-value†	Culvert 1A		Culvert 2A	
		Total Mass (kg)	Average Mass (g)	Total Mass (kg)	Average Mass (g)
DRP	0.002	0.9	39	3.5	129
TP	0.004	1.2	55	4.7	176
NH4-N	0.159	2.2	99	4.1	152
NO3-N	0.024	1.8	80	6.3	233
TN	0.021	5.6	256	15.4	571
TS	0.008	116	5273	454	17,450

* Parameters include dissolved reactive phosphorus (DRP), total phosphorus (TP), ammonium nitrogen (NH4-N), nitrate nitrogen (NO3-N), total nitrogen (TN), and total solids (TS)

† P-value is comparison of the masses across all sampling dates for Culverts C1A and C2A

Figure 5.1. Runoff Volumes at Culverts C1A and C2A as a Function of Time of Year

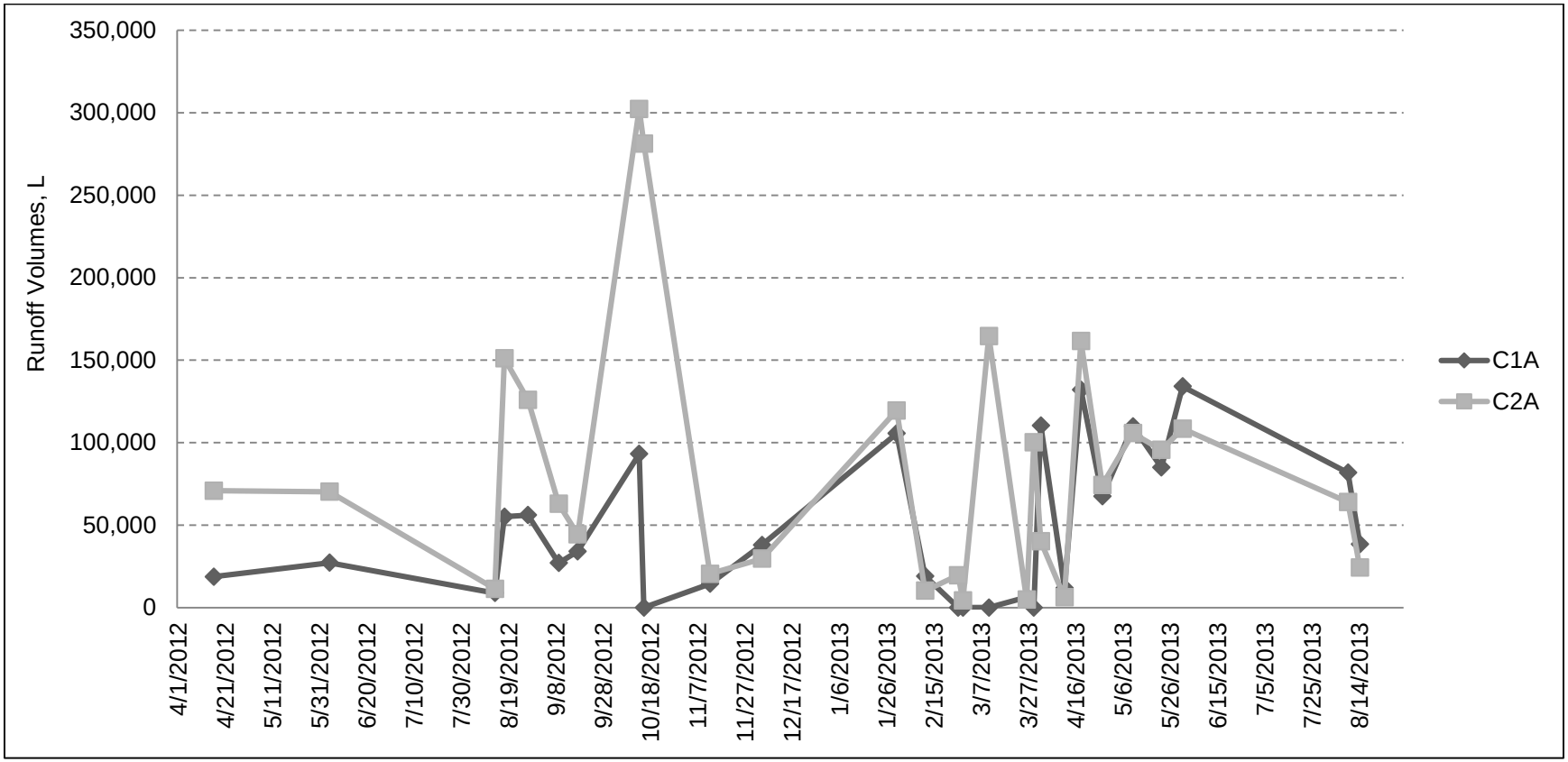

Figure 5.2. Rainfall Amount and Runoff Total Phosphorus and Dissolved Reactive Phosphorus Concentrations at Culverts C1A and C2A

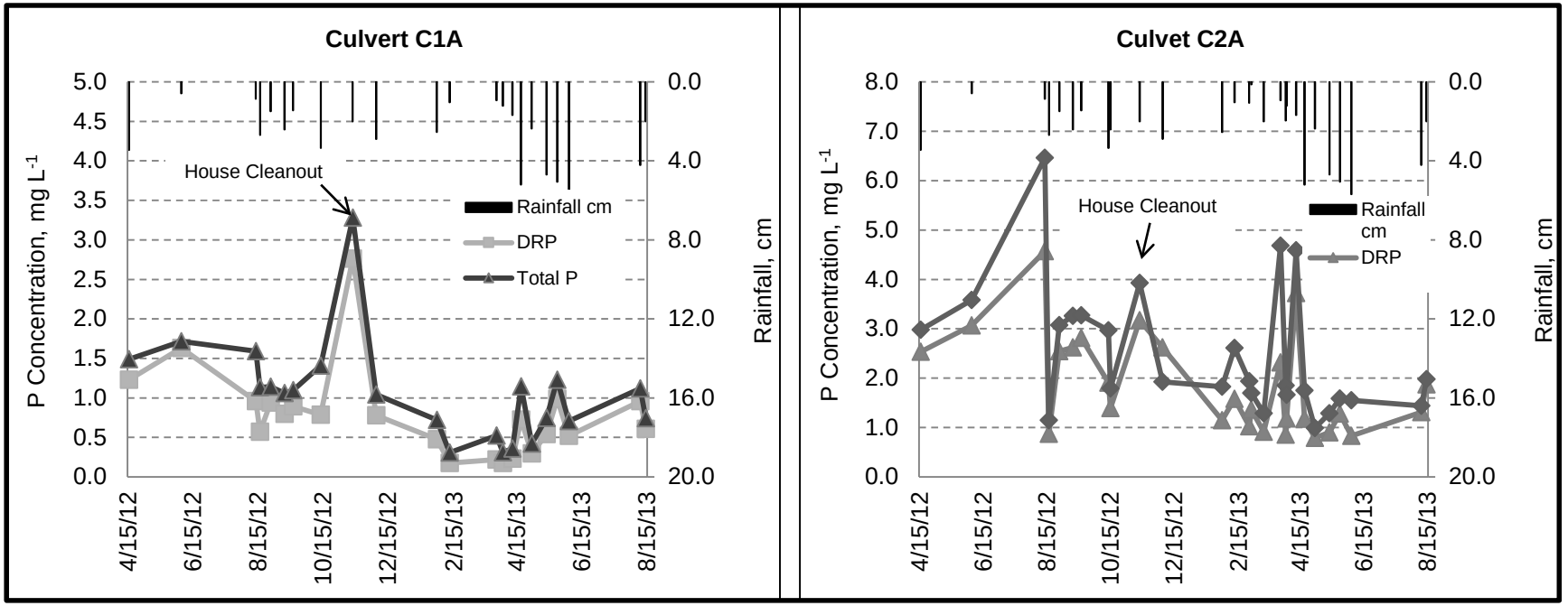

Figure 5.3. Rainfall Amount and Runoff Nitrogen Concentrations at Culverts C1A and C2A

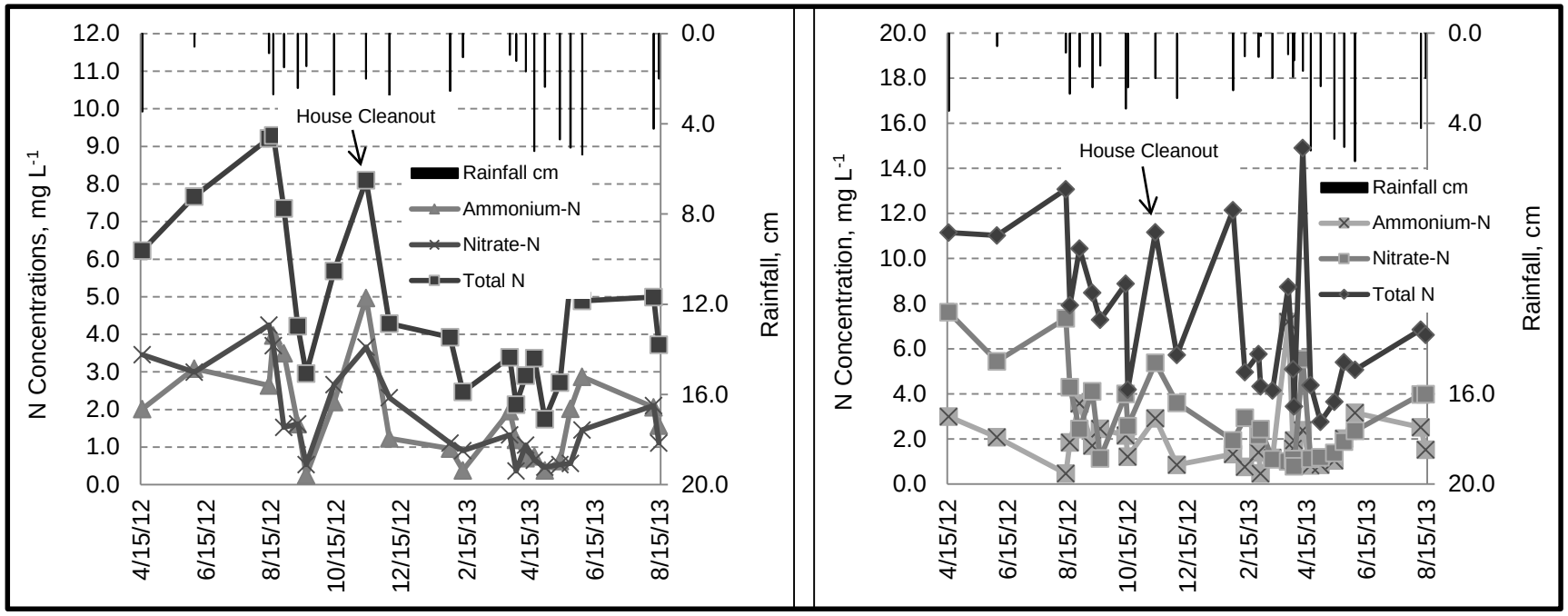

Image 5.1. Facility 2 Location of Culverts (C1A and C2A) that Transmit Rainfall Runoff from Between Houses, Where Automatic Samplers Were Installed

Adapted from image from Google Earth, 2012

Image 5.2. Automatic Sampler with Transducer and Suction Hose Installed in Culvert at Facility 2

Herron, 2012.

CHAPTER 6

OPTIMIZING HYDRAULIC AND CHEMICAL PROPERTIES OF IRON AND ALUMINUM BYPRODUCTS FOR USE IN ON-FARM CONTAINMENT STRUCTURES FOR PHOSPHORUS REMOVAL

OPTIMIZING HYDRAULIC AND CHEMICAL PROPERTIES OF IRON AND ALUMINUM BYPRODUCTS FOR USE IN ON-FARM CONTAINMENT STRUCTURES FOR PHOSPHORUS REMOVAL

Abstract

Phosphorus (P) transported in runoff from broiler production areas is a potential source for nutrient enrichment of local water bodies. Capturing the nutrients prior to runoff leaving the production area could reduce the risk of transport. Commercially available systems for nitrogen (N) and P removal from stormwater have been proposed to reduce nutrient concentrations in on-farm runoff, but are too expensive to be practical. The P adsorption capacities and hydraulic conductivities of iron filter cake, or red mud (RM), from a local source and aluminum water treatment residual (WT) were measured in order to determine their potential for use in on-farm treatment. The byproducts were air-dried and separated into ≤2-, ≤6-, and ≤12.5-mm particle size fractions. Phosphorus adsorption isotherms were constructed for the ≤2-mm fraction of each material. Langmuir equations were fitted to each of the isotherms and the P adsorption maximum for each material was determined by plotting the linearized forms of these Langmuir equations. The P adsorption maximum for RM was 25 g P kg^{-1} and the maximum for WT was 10 g P kg^{-1}. Hydraulic conductivity (HC) was also determined for each particle-size fraction using the constant head method, and results were evaluated for the material's ability to transmit a 25-year, 30-minute storm of 6.6 cm. The ≤2-mm particle-size fraction could not be completely saturated, resulting in inconsistent HC, so the results were not used in the final calculations. The HC of the ≤6-mm particle-size fraction of each byproduct did not differ, and averaged 4.1 cm min^{-1} for RM and 4.6 cm min^{-1} for WT. The HC of ≤12.5-mm particle-size fraction of each byproduct did differ, and averaged 8.0 cm min^{-1} for RM and 15.4 cm min^{-1} for WT. The HC of the RM ≤6- and ≤12.5-mm particle-size fractions did not differ, while the HC of the WT ≤12.5-mm particle-size fraction was greater ($p < 0.05$) than the ≤6-mm particle-size fraction. All of the byproduct particle-size fractions transmitted sufficient flow to accommodate the baseline storm. Phosphorus removal studies were conducted for the three particle size fractions for each byproduct utilizing the same columns and materials from the HC study. In each case, the solution applied to the column contained 6 mg P L^{-1}. Subsamples of column leachate were collected at initial flow and every 2 minutes thereafter for 30 minutes. An average of 98 and 84% of added P was sorbed by the ≤2-mm fraction of RM and WT, respectively. The ≤6-mm fraction of RM and WT sorbed 56 and 57% of

added P, respectively, and the ≤12.5-mm fraction sorbed only 28 and 10% of added P, respectively. The results of these experiments are integral to the design and operation of on-farm P removal systems utilizing the RM and WT byproducts.

Introduction

Runoff from the land directly around broiler production facilities has been shown to be enriched with nutrients that can contribute to water quality impairment (see Chapter 5). Nutrient concentrations in runoff can increase with increasing proximity to the nutrient source. Removing nutrients from runoff water prior to the runoff leaving the production area is more cost-effective than treating the resulting water impairment if the potential exists for runoff to reach a nearby stream or lake (Sharpley et al., 2012; U.S. Department of Agriculture and Environmental Protection Agency, 1999). In the case of N, NH_4^+ can readily be removed using a sufficiently sized grassed waterway over a soil with moderate permeability. Once in the soil, NH_4^+ is typically converted to nitrate (NO_3^-) and utilized by the grass (Brady and Weil, 1999). Particulate P can also be removed by the same grassed waterway; however, plants need less P than N, which can eventually lead to a build-up in the soil and the excess P can be transported offsite in runoff (Daniel et al., 1998). Removal of dissolved P from surface flows is more limited than for particulate P and most remedial measures for dissolved P focus on removal of P as close to the source as possible (Sims and Kleinman et al., 2005; Sharpley et al., 2006). Therefore, best management practices (BMPs) that trap P prior to the P leaving the production area are needed.

Several P removal systems, primarily designed for municipal and construction site stormwater treatment, are commercially available including the SkimBoss Floating Skimmer, developed by Suntree Technologies (i.e. a box-type removal system that is set inside a drain (Image 6.1)), the Filtrexx EnviroSoxx, developed by Filtrexx Sustainable Technologies (i.e. a long sock-type removal system containing proprietary P sorbents through which contaminated water flows (Image 6.2)), and a stormwater overflow weir filled with gravel-sized steel slag designed at Oklahoma State University (Image 6.3). The effectiveness of the SkimBoss and Filtrexx systems is limited by their low hydraulic conductivity which causes restricted flow through the P-removal media due to the size fractions used, resulting in overflow or bypass and reduced P removal. The coarser size fraction used in the overflow weir design is adequate for

hydraulic transmission, but results in reduced reaction time, which can reduce P removal from solution (Vohla et al., 2011).

Materials specifically manufactured to adsorb P tend to be costly and are, therefore, impractical for use at a broiler production facility. However, industrial byproducts with high P-adsorption capacities do exist. Water treatment residuals (WT) are one such class of byproducts. They are produced in large quantities by municipal drinking water plants when coagulants, such as alum, are added to raw water to flocculate solids suspended in the water. The Beaver Water District plant in northwest Arkansas uses alum as a flocculant and the resulting "floc" is skimmed from the treated water and centrifuged to remove free water (Bishop et al., 1991), then disposed of in landfills.

Another product that may be potentially useful is an iron-rich mud produced by Bekaert Corporation in Rogers, Arkansas. Bekaert manufactures steel belts for steel-belted, radial-ply tires. During the steel production process, wastewater is created which contains ferrous iron, hydrochloric acid and phosphoric acid. Bekaert collects the waste stream and adjusts the pH to greater than 8.5 with calcium hydroxide to create metal hydroxides. Next, an ionic polymer is added to bulk the metal hydroxides into larger flocs. Finally, the larger flocs pass through a plate and frame press to remove water, and the resulting final product is a waste material, which Bekaert refers to as iron filter cake or red mud (RM), so named due to its reddish appearance. This RM is captured at the manufacturing facility in a dumpster and is disposed of in landfills.

Products similar to these have been determined to be safe for handling and are known for their P-sorbing capacities (Vohla et al., 2011). These byproducts, once dried, display adsorption characteristics similar to iron and aluminum oxides. The objective of this study was to evaluate the P-adsorption characteristics and water transmission characteristics of WT and RM byproducts that may have potential for use as P adsorbing materials in on-farm P removal systems. It was hypothesized that the WT and RM byproducts would have large P-adsorption capacities. However, WT contains P due to its use as an adsorbent to remove P in the drinking-water filtration process, and RM contains P due to the use of phosphate as a cleaner in the manufacturing process to produce steel belts. Additionally, it was hypothesized that larger particle-size fractions of each of the byproducts would have greater HC and lower P-sorbing capacities than smaller particle-size fractions.

Materials and Methods

Experimental Design

To test the first hypothesis, an experiment was designed for a batch equilibration study with the independent variable being solution P concentration, and the dependent variable being P removal from solution. A randomized block design with three replications for each P concentration tested was used to evaluate P adsorption of each byproduct at different solution P concentrations.

To test the second hypothesis, experiments were designed with the independent variable being particle size. The dependent variable for the HC experiment was hydraulic transmission rate, and for the P removal experiment was P removal from solution. To control variability between replications, the byproducts were further separated into particle-size fractions (≤2-, 2-4-, 4-6-, 6-8-, and 8-12.5-mm diameter) and apportioned by percent volume of total to each column based on the particle-size fraction being tested (≤2-, ≤6-, or ≤12.5-mm diameter). A randomized block design with three replications of three samples for each byproduct particle-size fraction was used to compare hydraulic conductivities and P removal of the particle-size fractions.

Byproduct Selection and Particle Sizing

Iron filter cake was obtained from Bekaert Corporation and water treatment residual was obtained from Beaver Water District. The byproducts were loaded onto a tarp-lined flatbed trailer. The WT was either pressed through a 6-mm screen or separated into 10-cm diameter pieces prior to air drying for 48 hours on tarps on a concrete surface, and the RM was separated into 10-cm diameter pieces prior to air drying for 48 hours on tarps on a concrete surface. Following drying, the larger WT pieces and RM were crushed to smaller particle sizes using a roller.

Because both P adsorption and hydraulic conductivity will be affected by byproduct particle size, particle-size fractions were selected to contain small particle sizes for maximum P adsorption and larger particle sizes to allow for sufficient hydraulic conductivity. Screen sizes were chosen based on availability of wire mesh, 6.35-mm (¼-inch) and 12.7-mm (½-inch) diameter, for processing large volumes of material. The byproducts shrink during the drying process, resulting in a mixture of particle sizes ranging

up to the mesh size of the screen. Further crushing was required to get the materials to pass a 2 mm screen. Once dried, samples were sieved into particle-size fractions of diameter ranges ≤2-, ≤6-, and ≤12.5-mm. Byproducts were placed in sieves and were hand shaken from an angle of 300 degrees to 0 degrees, rotating every 15 seconds for a total shake time of one minute. The volume of each particle-size fraction was determined by placing the material level in a rectangular-shaped container, and measuring the length, width and height in cm (Table 6.1).

Columns were constructed for the hydraulic conductivity and P adsorption experiments (Figure 6.1). Individual 25.4-cm-long columns were cut from 3-m-long sections of 7.62-cm-diameter polycarbonate tubing. Holes were drilled, one near the top and one near the bottom of each column, and tube connectors were attached for the inlet and outlet. Rubber stoppers were glued to the bottoms. One end of 0.95-cm tubing was attached to the inlet connector and the other to a funnel, mounted on a stand at a height to create 5 cm of hydraulic head. Another section of 0.95-cm tubing was attached to the outlet connector and the end of the tubing directed into a collection container. An 18-L shower bag was used as the reservoir to supply flow, regulated with a hose clamp, to the funnel to maintain a constant head.

Initial Analyses

The byproducts were analyzed for existing nutrient content prior to conducting additional analyses. Parameters measured were P, nitrogen (N), potassium (K), and pH.

Isotherms

Phosphorus adsorption capacities were determined by constructing adsorption isotherms from data obtained by batch equilibrations using the ≤2-mm size fractions of each byproduct with solutions containing varying amounts of P. This test provided values representing the remaining adsorption capacities, above the amount sorbed to the materials as received. Monopotassium phosphate was used as the source of P for batch experiments. Fifty-milliliter centrifuge tubes were filled with either 1 g of air-dried RM byproduct or with 1 g of air-dried WT byproduct. The tubes were filled with 40-mL solutions of varying P concentrations, capped and shaken end-over-end at 24.2 rotations per minute for 60 minutes at 25 ^{o}C. Both byproducts were initially treated with 150, 200, and 250 mg P L^{-1} (6, 8 and 10 mg P) prior to

selecting additional concentrations to create complete isotherms (Table 6.2). After shaking, samples were centrifuged (Beckman Coulter Allegra X-15R, Pasadena, CA) for 10 minutes at 5,250 x *g*, decanted, and filtered through 0.45-µm syringe membrane filters. Dissolved reactive phosphate (DRP) concentrations of were determined by the colorimetric molybdenum-blue method of Murphy and Riley (1962). Analyses were replicated three times for each byproduct. Phosphorus adsorbed was calculated as the amount of P added minus the amount remaining in solution after shaking.

Phosphorus adsorption isotherms were constructed by plotting the equilibrium solution P concentration (C) on the x-axis against P sorbed per unit weight of byproduct (x/m) on the y-axis, where x/m is calculated as the difference between the initial and final amounts of P in solution divided by the mass of byproduct (Figure 6.2).

Langmuir Equation: $x/m = K_1K_2C/(1+K_1C)$ (adapted from Syers et al., 1973) (2)

Where,

x/m = P adsorbed per unit weight of byproduct (g kg^{-1})

K1 = binding energy constant (L mg^{-1} P)

K2 = adsorption maximum (mg kg^{-1}) also referred to as P adsorption maximum or maximum P adsorption capacity

C = equilibrium P concentration (mg L^{-1})

Hydraulic Conductivity

Hydraulic conductivities (HC) of the byproducts were determined for each of the three particle-size fractions using an adaptation of a constant-head method to determine HC of saturated soils (Reynolds and Elrick, 2002). The apparatus shown in Figure 6.1 was designed to test water treatment residuals for release of P (Oliver et al., 2011), but was modified to be used to also measure the HC of the two materials. The final columns constructed for this study are shown in Photo 6.4. This method involved initial wetting, followed by test runs using the byproducts with constant head of pressure (5 cm) to push the fluid from the bottom upwards. The method was chosen in view of the fact that, once dried, the RM and WT byproducts are hydrophobic and do not slake when wetted, making it difficult to remove air

pockets and fully saturate the material. Earlier attempts to saturate from the bottom and then apply a constant head from the top of the column for the test run were unsuccessful due to blockage by air pockets. The method chosen allowed for improved flow and for a better comparison with real-world conditions.

Containers used to store the particle-sorted byproducts were weighed prior to and after placement of byproducts in the test column to ensure consistent bulk density within each repetition (Table 6.3). Glass wool was placed in the bottom of the column covering the inlet. A rubber ring and a wire screen were placed on top of the glass wool to hold the glass wool in place and create a level bottom, on top of which was placed 8 cm of byproduct. Another layer of glass wool, sandwiched between two wire screens, was placed on top of the byproduct, below the outlet, to eliminate particle floating.

Hydraulic conductivity determinations were performed in triplicate, utilizing tap water and P solution (described in next section, P Adsorption Column Study), on the three particle-size fractions of the RM and WT byproducts for 10 minutes. A constant head was maintained in the funnel using a hose clamp to control flow from the outlet tube of an 18-L hanging shower bag, used as the tap water reservoir.

Constant head hydraulic conductivity was calculated as:

$$K_s = (V*L)/(A*t*H) \quad (1)$$

Where:

K_s = Saturated Hydraulic Conductivity, cm min^{-1}

V = Volume of flow for 10 minute run, cm^3

L = Length of byproduct in column, cm

A = Internal area of column, cm^2

t = Time of run, min

H = Head, H2-H1, cm

P Adsorption Column Study

The same particle-size fractions and materials used in the HC determinations were used in a P adsorption column study. The experiment was designed to simulate field conditions, where the P solution

moves through the byproduct. Phosphorus adsorption in this system was expected to be lower than that observed in the batch equilibration studies described earlier due to limited contact time. The 18-L reservoir supplying the constant-head flow to the columns was filled with a solution containing tap water brought to a concentration of 6 mg P L^{-1}, which was based on the average flow adjusted runoff TP concentration from the simulated rainfall plots adjacent to the fans (described earlier in Chapter 4). Phosphorus adsorption analyses were performed in triplicate on the three particle-size fractions of both RM and WT byproducts. Outflow solutions were subsampled for analysis at the beginning of flow and every two minutes for a period of 30 minutes total, which yielded 15 samples for each replicate. Samples were filtered through 0.45-µm membrane filters. The DRP concentration of each filtrate was determined by the colorimetric molybdenum-blue method of Murphy and Riley (1962).

Statistical Analyses

A one-factor analysis of variance (ANOVA) was conducted on the results from the batch equilibration study for each byproduct to compare across replicates. A homogeneity of variance test was conducted to compare HC of the ≤6- and ≤12.5-mm particle-size fractions of RM and WT. A homogeneity of variance test was also conducted to compare P removal of the ≤2-, ≤6-, and ≤12.5-mm particle-size fractions of RM and WT. The data variances were not homogenous for either HC or P removal, which violated the requirements for a two-factor analysis of variance (ANOVA). Therefore, a one-factor analysis of variance (ANOVA) was conducted to evaluate the effect of byproduct on HC and effect of particle size on HC, and a one-factor ANOVA was conducted to evaluate the effect of byproduct on P-removal capacity and effect of particle size on P-removal capacity. All results are reported as statistically significant at the $p < 0.05$ level unless noted otherwise. Wolfram Mathematica (online beta version 2014, Wolfram, Champaign, IL) was used to conduct the statistical analyses.

Results and Discussion

Initial Analyses

The byproducts were analyzed for existing P content prior to conducting additional analyses and the RM contained 33.9 mg P g^{-1} and WT contained 1.2 mg P g^{-1}. However, the existing P concentrations

was not a concern due to the fact that P adsorbed by these materials is not released unless the material is acidified (i.e. dissolution of Fe and Al compounds) or becomes anaerobic (i.e. reductive dissolution of Fe compounds) (Chardon et al., 2012; Vohla et al., 2011). Initial N and K concentrations in the RM were below detection limits of 1.0 mg kg^{-1} for N and 100 mg kg^{-1} for K. The WT initially contained 7,700 mg kg^{-1} total N and 1,400 mg kg^{-1} K. Both byproducts had a pH of 7.0.

Isotherms

The isotherm test provided values representing the remaining adsorption capacities, above the amount sorbed to the materials as received. Results for replicates did not differ ($P > 0.97$; Table 6.2). The RM byproduct removed over 90% of the added P up to the application rate of 13 mg P g^{-1} to the byproduct (Table 6.2). The WT byproduct removed over 90% of P up to the application rate of 3 mg P g^{-1} to the byproduct (Table 6.2).

Both isotherms were L-curve type isotherms, so Langmuir equations were used to describe the isotherms. The linearized form of the Langmuir equation was used to determine if the isotherms fit the Langmuir equation, and if so, to determine K_1 and K_2. The linearized form of the Langmuir equation is:

$$C/x/m = (1/K_1K_2) + C/K_2. \quad (3)$$

A plot of C/x/m against C should be a straight line if the Langmuir equation describes the isotherm, and the slope of the line is equal to $1/K_2$. As shown in Figure 6.3, the Langmuir equation described these isotherms well ($R^2 > 0.96$). The calculated maximum P adsorption capacity (P_{max}) ($=K_2$) was 25 mg P g^{-1} for RM and 10 mg P g^{-1} for WT. Table 6.4 summarizes previously reported P_{max} values for several P-sorbing materials. They range from 0.0003 mg P g^{-1} for limestone to 31.97 mg P g^{-1} for West Virginia ochre, an iron mining byproduct. The P_{max} value for RM was greater than 87% of the materials listed and that for WT was greater than 74% of those listed.

Hydraulic Conductivity

Variability in HC for all byproduct particle-size fractions was observed between each 10-minute replication within individual repetitions, and appeared to be a result of particle settling in the columns. Hydraulic conductivity was greater in the first 10-minute replication than the last two 10-minute

replications in 60% of the replications for all particle sizes of RM. The HC replications varied by 3.4, 3.1, and 10.5 cm min^{-1} for RM particle-size fraction treatment combinations of ≤2-, ≤6-, and ≤12.5-mm, respectively. Hydraulic conductivity was greater in the first 10-minute replication than the last two 10-minute replications in 100% of the runs for all particle sizes of WT. The HC replications varied by 0.6, 3.2, and 56.6 cm min^{-1} for WT particle-size fraction treatment combinations ≤2-, ≤6-, and ≤12.5-mm, respectively. Due to the variability in HC for the majority of the replications for all particle-size fraction treatment combinations of both byproducts, the first 10-minute replications were treated as conditioning runs to allow for byproduct settling. Therefore, results from the first 10-minute replications were not included in the final calculations.

Hydraulic conductivity varied notably for both the RM/ and WT/≤12.5-mm particle-size fraction treatment combinations. The HC of the RM/≤12.5-mm particle-size fraction treatment combination ranged from 8.3 to 25.7 cm min^{-1}, and that for the WT/≤12.5-mm particle-size fraction treatment combination ranged from 15.7 to 75.0 cm min^{-1}. The greater range in HC with the larger byproduct particle size was likely at least partially related to variability in capillary flow due to finer particles settling and clogging pores, which was noticeable when the material was removed from the columns in layers following completion of the study. The ≤2-mm particle-size fraction treatment combination for both byproducts showed visible dry material in the interior of the column following the study, indicating that they did not fully saturate in the column. Due to the ineffective test method for the ≤2-mm particle-size fraction treatment combination, the results for the treatment combination was determined to be invalid.

Comparison of HC data for ≤6-mm and ≤12.5-mm particle-size fraction treatment combinations for each byproduct yielded no difference ($p > 0.05$) in HC between RM/≤6-mm particle-size fraction treatment combination and RM/≤12.5-mm particle-size fraction treatment combination (Table 6.5). There was a significant difference ($p = 0.02$) in HC between the WT/≤6-mm and the WT/≤12.5-mm particle-size fraction treatment combinations, with the ≤12.5-mm particle-size fraction treatment combination averaging five-fold greater HC (Table 6.5). There was no difference ($p > 0.05$) in the HC between the ≤6-mm particle-size fraction treatment combination or between the ≤12.5-mm particle-size fraction treatment combination for both byproducts (Table 6.5). However, total flow volume for the RM/≤12.5-mm particle-size fraction treatment combination was almost twice that of the ≤6-mm and for the WT/≤12.5-mm

particle-size fraction treatment combination, the flow volume was over three times that of the WT/≤6-mm particle size-fraction treatment combination (Table 6.5).

Hydraulic conductivities were evaluated for sufficiency to support a 25-year 30-minute storm of 6.6 cm (0.22 cm min^{-1}) (U.S. Dept. of Commerce, 1961), which was increased 25 fold to 5.5 cm min^{-1}, to allow for potential flow restrictions from suspended particulate matter in stormwater. The measured HC for the RM/≤6-mm and RM/≤12.5-mm, and WT/≤12.5-mm particle-size fraction treatment combinations was above 5.5 cm min^{-1} in all replications, while the measured HC for the WT/≤6-mm particle-size fraction treatment combination was above 5.5 cm min^{-1} in all but one run. These results suggest that both byproducts at particle-size fraction treatment combinations of ≤6-mm and ≤12.5-mm could support water flow from a 25-year, 30-minute storm event.

P Adsorption Column Study

Columns containing the same byproduct used to determine the HC of each particle-size fraction were also used to estimate P adsorption. Although the experiment was designed to simulate field conditions, applying a constant head flow simulated extreme high flow conditions and resulted in reduced contact time between the P solution and the byproduct. The amount of solution that passed through the columns during the 30-minute sampling period varied with particle size. For the ≤2-mm particle-size fraction treatment combination, half as much solution was applied compared to the ≤6-mm particle-size fraction treatment combination, allowing for additional contact time between the P in solution and the byproduct particles. The ≤2-mm particle-size fraction treatment combination also had greater surface area for P adsorption to occur. This combination of factors resulted in 98% P removal for the RM/≤2-mm particle-size fraction treatment combination, and 94% P removal for the WT/≤2-mm particle-size fraction treatment combination (Table 6.6). However, the ≤2-mm particle-size fraction treatment combination did not have consistent HC.

The HC for both the RM and WT ≤6-mm particle-size fraction treatment combination were suitable for a 25-year, 30-minute storm. Additionally, both the RM and WT ≤6-mm particle-size fraction treatment combination sorbed greater than 56% of the added P, reducing the concentration from 6 mg L^{-1} to an average of 2.6 mg L^{-1} (Table 6.6).

Total flow volume for the RM/≤12.5-mm and WT/≤12.5-mm particle-size fraction treatment combinations was greater than that of the RM/≤6-mm and WT/≤6-mm particle-size fraction treatment combinations, respectively. There was significantly less surface area due to the larger average particle size. As a result, the RM/≤12.5-mm particle-size fraction treatment combination sorbed less than 30% and the WT/≤12.5-mm particle-size fraction treatment combination sorbed less than 11% of the P added in solution (Table 6.6).

Comparison of P removal data for ≤2-, ≤6-, and ≤12.5-mm particle-size fraction treatment combinations for each byproduct yielded significant differences ($p < 0.001$) between the particles-size fraction treatment combinations for both byproducts (Table 6.6). The RM/≤2-mm removed 42% more P than the RM/≤6-mm particle size treatment combination, the RM/≤6-mm removed 28% more P than the RM/≤12.5-mm particle size treatment combination, and the RM/≤2-mm removed 70% more P than the RM/≤12.5 particle-size treatment combination. The WT/≤2-mm removed 37% more P than the WT/≤6-mm particle size treatment combination, the WT/≤6-mm removed 47% more P than the WT/≤12.5-mm particle size treatment combination, and the WT/≤2-mm removed 83% more P than the WT/≤12.5 particle-size treatment combination. Additionally, there was a significant difference ($p < 0.001$) between RM and WT ≤2-mm particle-size treatment combinations, with RM removing 4% more P than WT (Table 6.6). There were no significant differences between RM and WT ≤6-mm particle-size treatment combinations (Table 6.6). Finally, there were significant differences between RM and WT ≤12.5-mm particle-size treatment combinations, with RM removing 18% more P than WT (Table 6.6).

Summary and Conclusions

The ≤2-mm particle-size fraction treatment combination of RM and WT byproducts had large P-adsorption capacities (P_{max}), 25 and 10 mg P g^{-1}, respectively, in spite of the P adsorbed to the raw byproducts when they were obtained. The P_{max} values for RM and WT were compared with other P adsorbents that have been evaluated, and the P_{max} value for RM was greater than 87% of the materials evaluated, and that for WT was greater than 74% of those evaluated. The P_{max} value of each byproduct is important for estimating the lifespan of any material that has the potential to be used for on-farm P removal systems.

Hydraulic conductivity data for each byproduct particle-size fraction treatment combination were evaluated for on-farm use by testing the effectiveness of the byproducts in a column to transmit 5.5 cm min^{-1} of rain water through the column. The HC for both byproducts' particle-size fraction treatment combinations of ≤6-mm and ≤12.5-mm were sufficient to transmit the baseline storm.

The P adsorption column study allowed testing of the three particle-size fraction treatment combinations of each byproduct in a manner more closely resembling field conditions than the batch equilibrium method used for the isotherm analyses. The ≤2- and ≤6-mm particle-size fraction treatment combinations removed greater than 50% of P in solution, indicating viability for use in on-farm P removal systems.

Successful design and operation of an on-farm P removal system utilizing the RM and WT byproducts would be dependent on both the HC and P removal potential of the select particle-size fraction treatment combination. Field testing of any design would be necessary to properly evaluate and ensure effectiveness.

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Table 6.1. Particle Size Distribution (by volume) of RM and WT Byproducts

Iron Filter Cake (RM)						
SIZE FRACTIONS	≤2 mm cm^3	≤2 mm % of Total	≤6 mm cm^3	≤6 mm % of Total	≤12.5 mm cm^3	≤12.5mm % of Total
8-12.5 mm	0.0	0%	0.0	0%	1592.0	32%
6-8 mm	0.0	0%	0.0	0%	1530.5	31%
4-6 mm	0.0	0%	902.1	30%	563.0	11%
2-4 mm	0.0	0%	831.4	27%	563.0	11%
<2 mm	1202.9	100%	1291.3	43%	688.2	14%
TOTAL	1202.9	100%	3024.8	100%	4936.8	100%
Alum Sludge (WT)						
8-12.5 mm	0.0	0%	0.0	0%	1592.0	31%
6-8 mm	0.0	0%	0.0	0%	1611.7	31%
4-6 mm	0.0	0%	1132.1	31%	638.4	12%
2-4 mm	0.0	0%	902.1	25%	572.3	11%
<2 mm	2211.1	100%	1645.1	45%	715.4	14%
TOTAL	2211.1	100%	3679.3	100%	5129.8	100%

Table 6.2. P Removed from Solution during Batch Equilibration ≤2 mm Particle Size RM and WT

mg L^{-1}	mg		%	P-value†
P Added	P Added	Average P Removed	Average P Removed	
Iron Filter Cake (RM)				
60	2.4	2.37	98.7%	0.98
90	3.6	3.55	98.7%	
120	4.8	4.74	98.7%	
150	6.0	5.82	96.9%	
200	8.0	7.73	96.7%	
250	10.0	9.53	95.3%	
325	13.0	12.07	92.8%	
425	17.0	15.08	88.7%	
500	20.0	17.15	85.8%	
1000	40.0	24.02	60.1%	
Water Treatment Residual (WT)				
50	2.0	1.8	92.1%	0.97
75	3.0	2.8	92.4%	
100	4.0	3.5	86.6%	
150	6.0	4.5	74.9%	
200	8.0	6.0	75.2%	
250	10.0	7.3	73.1%	
300	12.0	7.5	62.6%	
350	14.0	8.6	61.4%	

† P-value result of comparison across replicates for each byproduct.

Table 6.3. Bulk Density of Different Particle-size fractions of Iron (RM) and Aluminum (WT) Byproducts

Byproduct	Particle Size	Bulk Density g cm^{-3}
RM	≤2	0.82
	≤6	0.80
	≤12.5	0.87
WT	≤2	0.85
	≤6	0.86
	≤12.5	0.84

Table 6.4. Maximum Phosphorus Adsorption Capacities of a Variety of Materials that have been Considered as Phosphorus Adsorbents

Substrate	Pmax mg P g^{-1}	Reference
Ace ALD ochre	7.41	Sibrell et al., 2009
AMD flocs – Lime treated	0.73	Sekhon and Bhumbla, 2012
AMD flocs – NaOH treated	0.76	Sekhon and Bhumbla, 2013
AMD flocs – NH4 treated	0.86	Sekhon and Bhumbla, 2014
Apatite	0.28–1.09	Bellier et al., 2006
Avoca ochre	21	Fenton et al., 2009
Babb Creek ochre	1.82	Sibrell et al., 2009
Bauxite	0.61	Drizo et al., 2006
Blast Furnace Slag	0.40-0.45	Mann, 1997
Blast furnace slag	0.4	Mann, 1998
Bottom Ash	0.06	Mann, 1999
Burnt oil shale	0.65	Drizo et al., 2006
Coal ash	0.081 – 29.5	Yan et al., 2007
Dolomite	0.168	Prochaska and Zouboulis, 2006
Dolomite sand	0.417	Pant et al., 2001
Fly Ash	0.62	Mann, 1997
Fly ash	5.5 – 42.6	Chen et al., 2007
Friendship Hill ochre	23.9	Sibrell et al., 2009
Glen White Pond ochre	9.84	Sibrell et al., 2010
Gravel	0.03-0.05	Mann, 1997
Iron ochre (coal mine drainage treatment)	26	Dobbie et al., 2009
Iron-coated sand	27.4	Chardon et al., 2012
Laterite	0.75	Drizo, 1998
Limestone	0.0003 – 0.20	Johansson, 1999
Minto Ochre	30.5	Heal et al., 2004
Ochre pellets	22	Dobbie et al., 2009
Polkemmet Ochre	26	Heal et al., 2004
Randy Camp ochre	5.53	Sibrell et al., 2009
Sands (Danish)	0.02 – 0.129	Arias et al., 2001
Shale	0.75	Drizo, 1998
Shell sand	14 – 17	Roseth, 2000
Shell sand	0.8 – 8.0	Søvik an Kløve, 2005
Shell sand	9.6	Àdàm et al., 2007
Steel Slag	0.38	Mann, 1997
Toby Creek ochre	22.6	Sibrell et al., 2009
West Virginia ochre	31.97	Wei et al., 2008
Zeolite	1	Drizo, 1998
Zeolite	2.15	Sakedevan and Bavor, 1998

Table 6.5. Average and Variance of Hydraulic Conductivity (HC) of Iron Filter Cake (RM) and Water Treatment Residual (WT) as a Function of Byproduct Particle Size

Byproduct	Particle Size Fraction	Particle Size HC (cm min^{-1})		P-value†	
		Average	Variance		
RM	≤6 mm	10.6	14.6	RM ≤6 mm/≤12.5 mm	0.14
	≤12.5 mm	16.3	45.9	WT ≤6 mm/≤12.5 mm	0.02
WT	≤6 mm	8.0	4.1	RM/WT ≤6 mm	0.44
	≤12.5 mm	43.1	684.8	RM/WT ≤12.5 mm	0.054

† P-value is comparison of the HC between particle sizes and byproducts, as noted.

Table 6.6. Average and Variance of Phosphorus (P) Removal of Iron Filter Cake (RM) and Water Treatment Residual (WT) as a Function of Byproduct Particle Size

Byproduct	Particle Size Fraction	Particle Size P Removal		P-value†	
		Average	Variance		
RM	≤2 mm	98%	0.009	RM ≤2 , ≤6 , ≤12.5 mm	<0.001
	≤6 mm	56%	0.004	WT ≤2 , ≤6 , ≤12.5 mm	<0.001
	≤12.5 mm	28%	0.221	RM/WT ≤2 mm	<0.001
WT	≤2 mm	94%	0.118	RM/WT ≤6 mm	0.496
	≤6 mm	57%	0.052	RM/WT ≤12.5 mm	<0.001
	≤12.5 mm	10%	0.280		

† P-value is result of comparison of the P removal between particle sizes and byproducts, as noted.

Figure 6.1. Column Design for Phosphorus Adsorption Column Study, Also Used for Hydraulic Conductivity Determinations (adapted from Oliver, et al 2011)

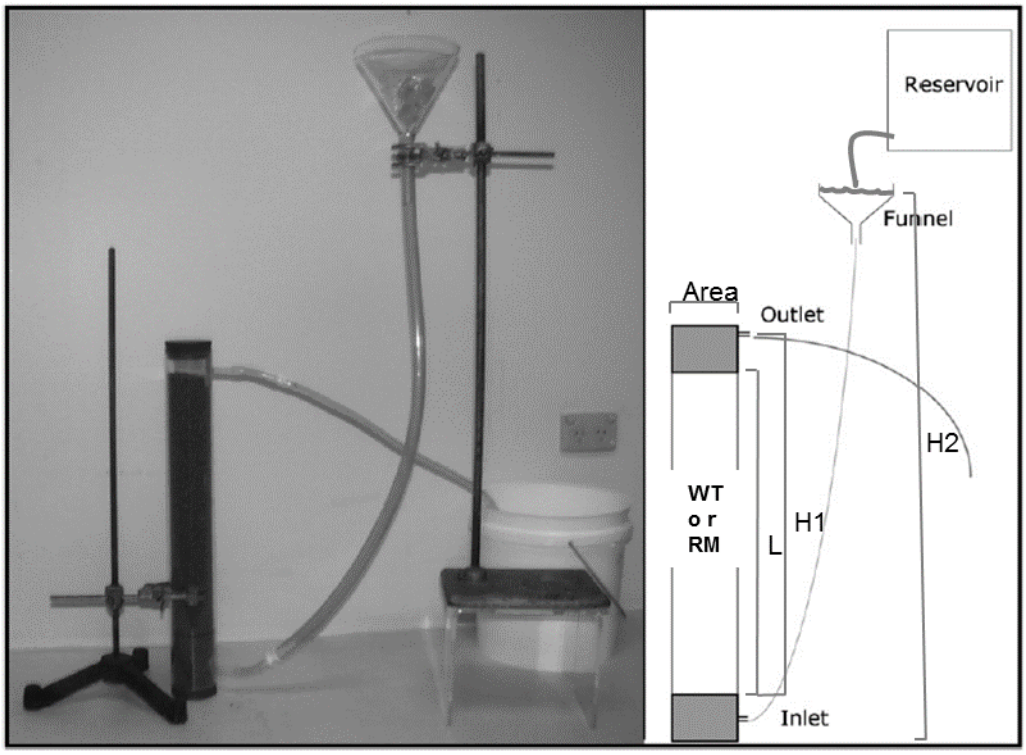


Figure 6.2. Phosphorus Adsorption Isotherms of ≤2 mm Particle-sized Byproducts

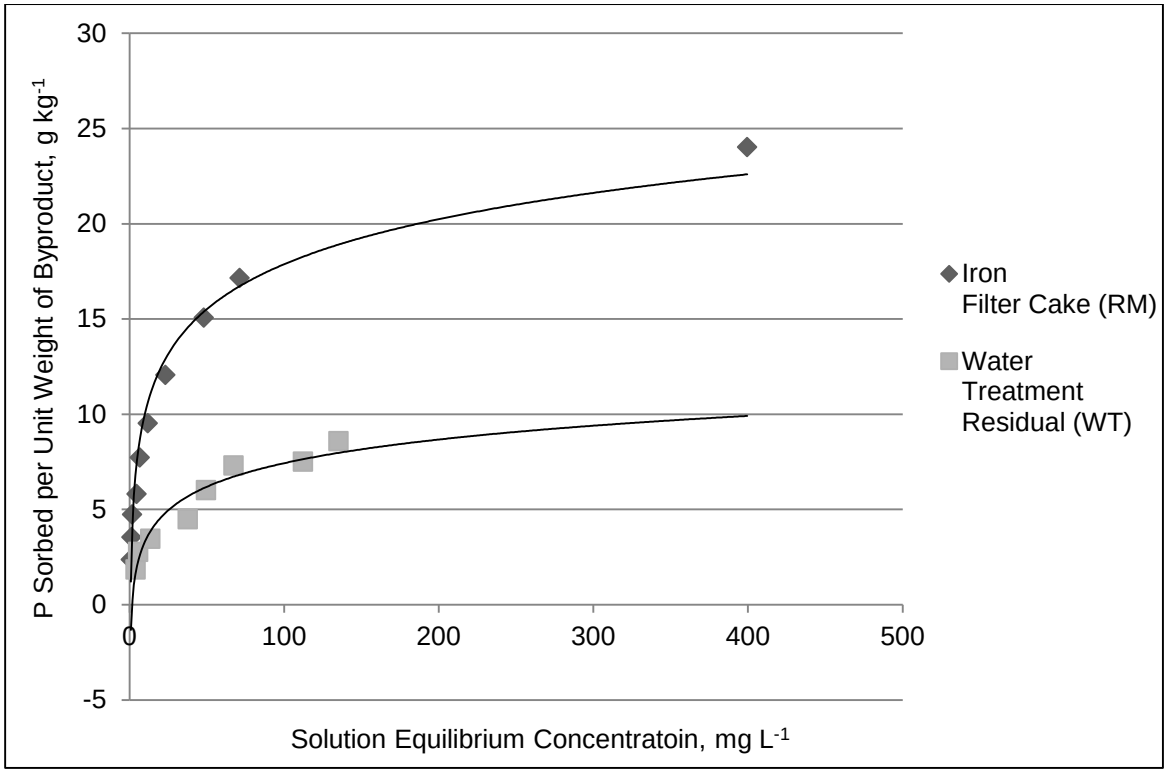


Figure 6.3. Description of the Isotherms by the Linearized Langmuir Equation

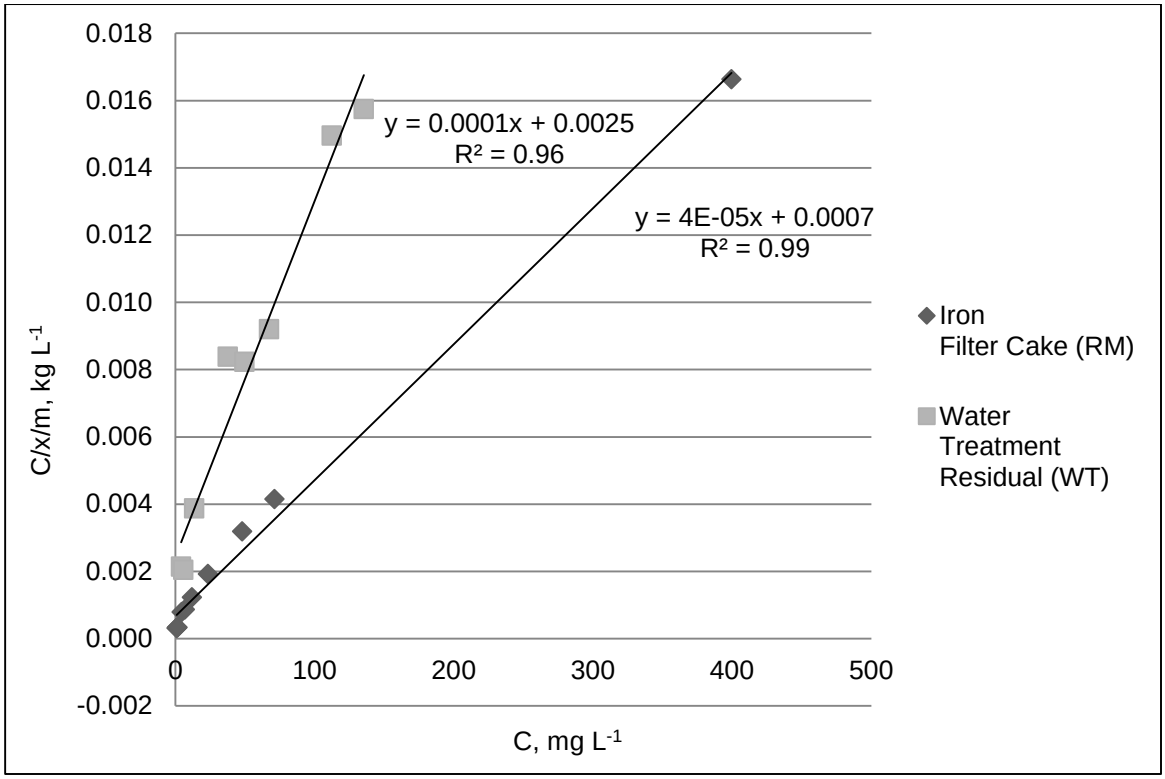
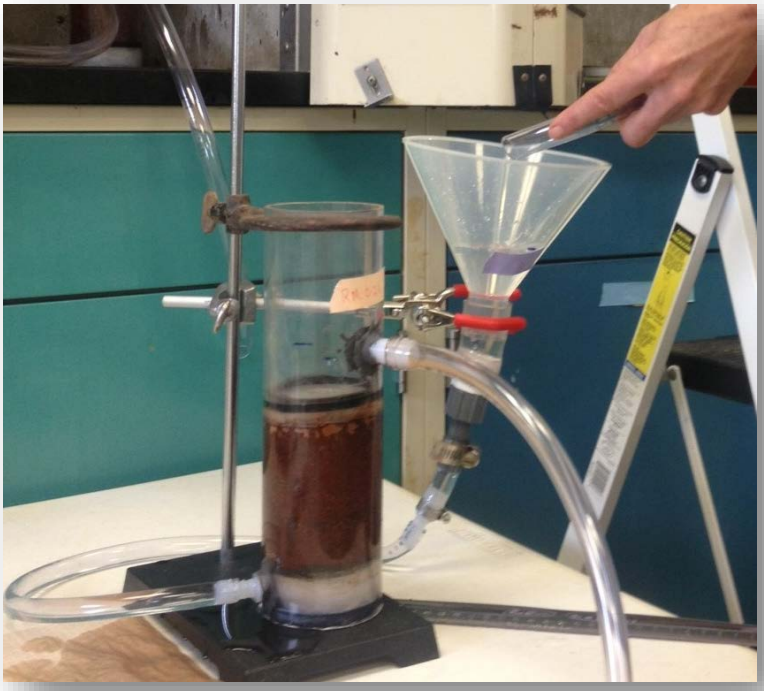


Image 6.1. Suntree Technologies Inc. SkimBoss Floating Skimmer (2014)

Image 6.2. Filtrexx Sustainable Technologies EnviroSoxx (2014)

Image 6.3. P Removal Weir (2014)

Image 6.4. Phosphorus Adsorption and Hydraulic Conductivity Column as Constructed for this Study



Herron, 2013.

CHAPTER 7

DESIGN AND TESTING OF NUTRIENT REMOVAL SYSTEMS USING LOCALLY-SOURCED IRON AND ALUMINUM BYPRODUCTS FOR REDUCING NUTRIENT CONCENTRATIONS IN RUNOFF FROM BROILER PRODUCTION FACILITIES

DESIGN AND TESTING OF NUTRIENT REMOVAL SYSTEMS USING LOCALLY-SOURCED IRON AND ALUMINUM BYPRODUCTS FOR REDUCING NUTRIENT CONCENTRATIONS IN RUNOFF FROM BROILER PRODUCTION FACILITIES

Abstract

A common issue with filters designed to remove nutrients from runoff is their reduced effectiveness in high-flow conditions. To overcome this challenge, it was determined that nutrient removal from broiler house fan dust could be more effective if nutrient removal were to be conducted at the nutrient source where the water volume is limited to rainfall on a small surface area. The objectives of this study were to design and construct containment structures to hold locally-sourced byproducts, and install and test them adjacent to a broiler house fan outlets to capture and remove broiler house dust nutrients prior to the nutrients entering rainfall runoff from the site. Leachate from the containment structure was collected and analyzed to evaluate the effectiveness of the design on water quality. The byproducts used in the study were locally-sourced alum-based water treatment residual (WT) and red mud-like material (RM) generated during the manufacture of steel belts for tires. These byproducts have large phosphorus (P) sorption capacities. A laboratory study was designed to test the nutrient-removal effectiveness of depths of 4, 8 and 12 cm of the RM and WT byproducts using 56.8-L buckets, adapted to function as leaching columns and miniature containment structures. The buckets were filled with byproduct to the specified thickness, and treated with a 3 mm thickness of broiler house dust prior to receiving 30 minutes of simulated rainfall at a rate of 7 cm hr^{-1}. Containment structures were designed and installed in April 2013 adjacent to four sidewall ventilation fans at the University of Arkansas Savoy broiler production facility (Facility 2). The 8-cm thickness of both RM and WT outperformed the other thicknesses in terms of sorbing P released from the added dust, where removal was 99 and 96% of the added P, respectively, and displayed no reduction in hydraulic conductivity. The 12-cm thickness of both RM and WT showed no additional benefit for HC or P removal over the 8-cm thickness. Thus, an 8-cm thickness of RM or WT was chosen to be used in the on-farm evaluation to reduce costs of manufacturing the structures and preparing the byproducts. Following installation of the containment structures at Facility 2, leachate was collected for 25 storm events over a two-year period. The byproducts reduced total P (TP) concentrations to an average of less than 0.90 mg L^{-1} for RM and 0.40 mg L^{-1} for WT.

Introduction

Nutrient concentrations in runoff from land around broiler production facilities can increase with an increase in proximity to the nutrient source (Chapters 4 and 5 of this thesis). Two major sources of nutrients are dust exhausted from the production houses by fans and the litter that is tracked from the houses during bird removal and clean-out (U.S. EPA, 2011). Accentuating this potential loss of nutrients, particularly P, is the fact that while the dust had a similar TP concentration to litter, the water solubility of dust P was on average three times greater than that in the litter (Chapter 3 of this thesis). Removing nutrients from runoff water prior to water leaving the production area is clearly the most cost-effective on-farm best management practice (BMP). Strategies to reduce nutrient runoff now target nutrient sources rather than treating receiving waters, in order to most cost-effectively decrease impairment (Sharpley et al., 2011; Stout et al., 1999; U.S. Department of Agriculture and U.S. Environmental Protection Agency, 1999).

To be consistently effective, P-removal systems must able to treat and transmit large volumes of runoff. As runoff volumes from the land around broiler production houses can easily overload available systems, these systems would not be consistently effective. In addition, the installation and maintenance of these systems is expensive and labor intensive, making them unrealistic as a permanent, on-farm solution. Removing P at the source avoids the issue of hydraulic overload because it would no longer be necessary to treat large volumes of runoff. This source management philosophy is consistent with recent EPA and NRCS initiatives, which focus on source control as the most cost-effective nonpoint-source remedial strategy. For instance, critical source area targeting has become the dominant paradigm for agricultural P management, as reflected by the widespread development and adoption of P site assessment indices (Sharpley et al., 2003). In fact, remedial strategies are most cost-effective if targeted at the source rather than treating impaired waters, and federal and state agencies have changed their strategic planning for nutrient management with respect to water quality impacts because eliminating the cause of degradation is less expensive than treating the negative impacts (Sharpley et al., 2011).

Described here is a treatment system that was designed as a containment structure to be recessed into the ground adjacent to the fan outlets and filled with P-sorbing materials. Dust from the broiler houses settles on top of the P-sorbing materials. During a rainfall event, rainfall first encounters the

dust and leaches nutrients from the dust into the underlying P-sorbing materials where they are removed. The bottom of the structure is elevated off the soil to allow for the filtered leachate to drain into the soil.

The effectiveness of such a containment structure is not only a function of the design and placement, but is also a function of the capacity of the retention media to capture and retain the target nutrients (Oliver et al., 2011; Vohla et al., 2011). To be most cost-effective, the P retention media need to be locally sourced, readily available, and inexpensive. Industrial byproducts with large P retention capacities that are currently being landfilled are ideal candidates if the byproducts do not contain hazardous materials. Two such byproducts are alum-based water treatment residuals (WT) generated where alum is used to flocculate suspended solids from raw municipal water supplies, and any of a group of byproducts variously referred to as red muds or iron filter cakes, which consist primarily of iron oxides and oxyhydroxides. The byproducts used in this study were an alum-based WT generated by the Beaver (AR) Water District, and an iron filter cake from Bekaert Steel in Rogers, Arkansas, that is generated during the manufacture of steel belts for tires. The P sorption characteristics and hydraulic properties of these materials have been described previously (Chapter 6).

The first objective of this study was to determine the optimum thickness of byproduct to be used in an on-farm treatment system. Following determination of the optimum thickness, the next objective was to construct, install and test an on-farm nutrient-removal system, or containment structure. The containment structures were to be installed recessed into the ground, adjacent to broiler house fan outlets, filled with either RM or WT byproduct, and studied for their ability to capture broiler house dust and remove nutrients prior to the nutrients being transported in rainfall runoff from the production area. It was hypothesized that an optimum thickness of byproduct for use in the on-farm containment structures could be determined. It was further hypothesized that an on-farm nutrient removal system could be designed to trap broiler house dust, and remove nutrients from the dust prior to the nutrients being transported with rainfall runoff.

Materials and Methods

Experimental Design

To test the above hypotheses, two experiments were designed. The first was a rainfall simulation study on a small-scale containment structure to test various thicknesses of byproduct for nutrient removal from broiler house dust (BHD). The structure was designed by adapting 56.8-L buckets to contain the WT and RM byproducts. Dust was applied to the treatments, followed by simulated rainfall applications to transport the dust through the byproduct. Leachate was captured and analyzed for nutrient concentrations. The two independent variables were byproduct thickness and applied dust. The dependent variable was nutrient concentration of the leachate. The SAS program (Version 9.3, SAS Institute Inc., Cary, NC) was used to design the randomized block design layout for the buckets under the rainfall simulator. Three byproduct thicknesses were tested in triplicate, and dust applications and rainfall simulations were replicated seven times.

The second experiment was designed to test the full-size containment structures on a facility, exposed to real-world conditions. The containment structures were installed recessed into the ground, over a visqueen catchment for leachate. A repeated measures design was used for four containment structures, two containing RM byproduct and two containing WT byproduct, to evaluate leachate nutrient concentrations over time.

As detailed in Chapter 6, hydraulic conductivity (HC) and P removal of each byproduct were determined for each of three particle-size fraction treatment combinations, ≤2-, ≤6-, and ≤12.5-mm. The HC test results of the ≤2-mm particle-size fraction treatment combination for both byproducts were determined to be invalid since air pockets within the byproducts in the column could not be removed and interfered with the test results. The ≤6 mm particle-size fraction treatment combination averaged 10.6 cm min^{-1} for RM and 8.0 cm min^{-1} for WT, and the ≤12.5-mm particle-size fraction treatment combination averaged 16.3 cm min^{-1} for RM and 43.1 cm min^{-1} for WT. The HC were initially compared to a 25-year 30-minute storm of 6.6 cm, however that volume was increased by 5 times to 33 cm based on the additional surface area on the roofs of the broiler houses and the ground surface above that would transmit runoff onto the surface of the containment structures. From this, it was determined that the HC for the ≤6 mm particle-size fraction treatment combination for RM averaged 10.6 cm min^{-1}, or 318 cm in

30 minutes, and for WT averaged 8.0 cm min^{-1}, or 241 cm in 30 minutes, which were determined to be more than adequate to transmit the calculated volume of rainfall and runoff. Although the ≤2-mm particle-size fraction treatment combination outperformed the ≤6 mm particle size group in the P removal study, the ≤6 mm fraction treatment combination of RM and WT removed 56 and 57% of added P, which was far superior to the ≤12.5-mm particle size group of both RM and WT. Therefore, the ≤6 mm particle size group for both RM and WT was chosen as the most suitable for use in the on-farm treatment system.

Containment Structure Design

Containment structures were constructed of polyvinylchloride side boards (1.9-cm thick and 22.9-cm wide) and vinyl-coated welded wire mesh bottoms (Image 7.1). The interior dimensions of the structure constructed for use adjacent to sidewall ventilation fans at Facility 2 were 1.2-m wide by 1.8-m long. Structures were sized for the particular location, and were designed to capture the majority of the dust particles where they were deposited. Landscape fabric lined the bottom and inner sides of the containment structure and was used to contain the byproduct and trapped contaminant. Rain falling on the containment structures leached the dust through the byproduct, trapping particulate matter and sorbing P. A 10.2-cm free air space below the byproduct allowed for leaching of solutions with reduced P and nitrogen compounds into soil, which minimized risk to area water quality (Figure 7.1).

Rainfall Simulation on Byproducts Treated with Broiler House Dust

Three thicknesses of the byproducts, 4, 8 and 12 cm, were tested using 56.8-L buckets. The bottoms of 27 buckets were removed, leaving space for the thickness of the byproduct plus 33 cm of freeboard at the top. Welded wire mesh, 1.3-cm diameter, was attached to the bottom of the buckets for support. Landscape fabric was sewn to the shape of the buckets and placed on top of the wire mesh. The byproduct was placed inside the landscape fabric. The cut buckets were placed inside uncut 56.8-L buckets, perforated on the sides to allow for air flow, to capture leachate during the experiment (Figure 7.2). Samples were run in triplicate, including controls for each byproduct that received no dust treatments, and dust only treatments with no byproduct.

Broiler house dust collected from fan shutters from four broiler facilities in northwest Arkansas was combined and mixed thoroughly in a 113.6-L barrel (see Chapter 3). The dust application rate for the experiment was calculated based on measured thicknesses of dust settled on the ground adjacent to fan outlets during one grow-out of birds (approximately 6 weeks), which averaged 3.2 mm per flock. Based on the surface area of the bucket (638 cm^2) and the bulk density of the dust (0.23 g cm^{-3}), measured by weighing 10 subsamples of the dust in the barrel in a 50-cc container, 45.43 g of dust were used for each treatment. The dust was analyzed by the University of Arkansas Agricultural Diagnostic Laboratory and contained 4,312 mg water extractable P kg^{-1}, 10,400 mg total P kg^{-1} , 3,785 mg NH_4-N kg^{-1}, and 277 mg NO_3-N kg^{-1}. The dust was carefully sprinkled on top of each bucket receiving treatments prior to rainfall simulation to create a uniform surface layer.

The rainfall simulator utilized was based on the design of Miller (1987). The frame was built of hollow metal tubing upon which was mounted a 25-mm diameter PVC water supply pipe. Polyvinyl chloride windscreens were attached to the four sides to limit wind effects on rainfall distribution. A water hose supplying water from the city water supply was attached to a 25-mm diameter PVC water supply pipe. A single fixed nozzle (TeeJet™ 1/2HH-SS-5OWSQ), designed for a flow rate of 210 mL sec^{-1}, was installed on the water supply pipe, centered at the top of the frame and 3 m above the surface of the plot (SERA-17, 2013). The simulator was elevated on concrete blocks to create a 3-m separation between the simulator nozzle (water source) and top of the buckets. A low-pressure regulator and an oil-filled pressure gauge were used to maintain pressure at 37.9 kPa (5.5 PSI). An in-line filter was placed in the supply pipe to prevent large particles from clogging the line and nozzle.

The buckets were placed under the rainfall simulator in three zones (one for each replicate) and in randomized order as determined by Statistical Analysis System (SAS) (Table 7.1 and Figure 7.3). Rainfall intensity was verified and uniformity of distribution was determined by simulating rainfall onto the buckets for 15 minutes, measuring the volume collected, and replicating twice. The locations of the zones were selected based on the results of the uniformity tests. The coefficient of uniformity (CU) was then determined using Christiansen's (1942) method, which expresses CU as a percentage with the formula $CU = 100(1.0 - \Sigma d / m * n)$ where d is the standard deviation of individual observations from the mean value m, and n is the number of observations (Humphry et al., 2002). Percent uniformity was

calculated by dividing the average deviation of the volumes from the average volume by the average group volume (Kara et al., 2008).

Rainfall simulations were conducted at an intensity of 7 cm hr^{-1} (2-year 24-hour storm rate) and leachate was collected for a total of 30 minutes, according to the National Phosphorus Research Project (SERA-17, 2013). Samples received 30 minutes of simulated rainfall prior to the first treatment with dust. After the first rainfall simulation, dust was surface applied to the byproducts in each bucket, which then received simulated rainfall. This procedure was repeated for a total of six consecutive dust applications and 30 minutes of 7 cm hr^{-1} rainfalls. Six dust applications approximated the amount of dust deposited on the soil by a broiler house fan during one year of typical operation.

Following each rainfall simulation, leachate was collected from the bottom buckets. The volume was measured and a 1-L subsample was retained from each bucket for chemical analysis. Subsamples were refrigerated and delivered to the University of Arkansas Division of Agriculture Water Quality Laboratory within 24 hours of collection. Source water used for the simulated rainfall was from the tap, which was also sampled and prepared identically for analyses. Forty milliliters were filtered through 0.45-µm membrane filters immediately after collection and stored at 4 ^{o}C until analyzed for dissolved reactive phosphorus (DRP) by the colorimetric molybdenum-blue method of Murphy and Riley (1962). Ammonium nitrogen (NH_4-N) and nitrate nitrogen (NO_3-N) were analyzed colorimetrically by flow injection analyses (Lachat Instruments QuikChem 8500, Loveland, CO). One hundred twenty-five milliliters were acidified to a pH ≤2 with concentrated sulfuric acid for sample preservation, and analyzed for total phosphorus (TP) and total nitrogen (TN) using persulfate/autoclave digestion (Patton and Kryskalla, 2003). Total P was determined by spectrophotometry (Beckman Coulter, Pasadena, CA), and TN was determined by flow injection analysis (Lachat Instruments QuickChem 8500, Loveland, CO). One hundred twenty-five milliliters were analyzed for total solids (TS) gravimetrically after oven-drying at 105 ^{o}C for 12 hours.

Following the first and final rainfall simulation on the 12-cm-thick-treated and control samples of each byproduct, leachate was collected and filtered through 0.45-µm membrane filters. Filtered samples were delivered to the Centre for Ecology and Hydrology at Lancaster, UK. A suite of major cations (boron, calcium, potassium, magnesium, sodium, and silicon) were assayed using a Perkin Elmer DV7300 inductively coupled plasma optical emission spectrometer, ICP-OES) together with a suite of

trace elements (aluminum, arsenic, barium, beryllium, cadmium, cerium, cobalt, chromium, cesium, copper, lanthanum, lithium, manganese, molybdenum, nickel, lead, praseodymium, rubidium, antimony, selenium, tin, strontium, titanium, uranium, vanadium, tungsten, and zinc) by inductively coupled plasma mass spectrometer (Perkin Elmer Models Elan DRC 11 and Nexion 300D, Waltham, MA).

Installation of Containment Structures

Four containment structures, 1.2-m wide by 1.8-m long, were designed and built for installation adjacent to four sidewall ventilation fans at Facility 2. Structures were installed in April 2013. The structures were recessed into the ground so the top of the frame closest to the fan outlet was level with the ground. The structures were installed level so rainfall would percolate through the dust and byproduct evenly. The soil below and along the sides of the containment structures was lined with 6 mm PVC sheeting to capture leachate for analyses (Image 7.2). The mesh covering the containment structures helped retain dust exhausted from the ventilation fans (Image 7.3). A 2.5-cm interior diameter PVC pipe was installed at one corner to allow access for a pump tube to collect the leachate, which was accomplished using a long, flexible tube, connected to a peristaltic pump.

Containment Structure Leachate Collection and Analyses

Following storm events that generated runoff at Facility 2, leachate was collected from beneath the containment structures. Leachate was subsampled and 1 L was retained from each structure for analyses. Subsamples were refrigerated and delivered to the University of Arkansas Division of Agriculture Water Quality Laboratory within 24 hours of collection. Forty milliliters were filtered through a 0.45-µm membrane filter immediately after collection and stored at 4 ^{o}C until analyzed for DRP by the colorimetric molybdenum-blue method of Murphy and Riley (1962). Ammonium-N (NH_4-N) and nitrate-N (NO_3-N) were analyzed colorimetrically on by flow injection analysis (Lachat Instruments QuickChem 8500, Loveland, CO). One hundred twenty-five milliliters were acidified with 12 drops of concentrated sulfuric acid for sample preservation, and analyzed for TP and TN using persulfate/autoclave digestion (Patton and Kryskalla, 2003). Total P was determined by spectrophotometry (Beckman Coulter, Pasadena, CA), and TN was determined by flow injection analysis (Lachat Instruments QuickChem 8500,

Loveland, CO). One hundred twenty-five milliliters were analyzed for TS gravimetrically after oven-drying at 105 ^{o}C for 12 hours.

Statistical Analyses

The TP results of the buckets study analyses were tested for and had homogeneous variances. Therefore, a two-factor analysis of variance (ANOVA) was conducted on the bucket study outflow concentrations of TP to evaluate the effects of byproduct, byproduct thickness, and their interaction. Separate one-factor ANOVAs were conducted on the bucket study outflow concentrations of DRP, NH_4-N, NO_3-N, and TN, which did not have homogeneous variances, to evaluate for differences between byproducts and thickness. A one-factor ANOVA was conducted on the containment structure outflow concentrations of DRP, TP, NH_4-N, NO_3-N, and TN, which did not have homogeneous variances, to compare for differences among the containment structures. All relationships are reported as statistically significant at the $p < 0.05$ level unless noted otherwise. Wolfram Mathematica (online beta version 2014, Wolfram, Champaign, IL) was used to conduct the statistical analyses.

Results and Discussion

Simulated Rainfall Distribution

Although the layout of the buckets for the rainfall simulation study was determined using SAS (Figure 7.3), the actual location of the buckets under the rainfall simulator (Image 7.4) was adjusted based on rainfall distribution uniformity. The average uniformity for group 1 was 95%, 94% for group 2, and 87% for group 3, as determined by SAS coefficient of uniformity (Table 7.2). Additionally the coefficient of uniformity among three consecutive 30-minute, 7 cm hr^{-1} rainfalls was 93%. Thus, it was concluded that the column leachate experimental set up using buckets in the rainfall simulator gave repeatable results for the applied rainfall both within the simulator footprint and among individual rainfalls. For instance, coefficients of uniformity of 90% to 93% were considered excellent by Miller (1987) and Humphry et al. (2002), and the National Phosphorus Research Project protocol (SERA-17; 2014) recommends 85% uniformity or greater for standardized rainfall simulations using the same equipment and procedures.

Rainfall Simulation on Byproducts Treated with Broiler House Dust

Outflow concentrations for all thicknesses of RM ranged in DRP from 0.001 to 1.8 mg L^{-1}, in TP from 0.28 to 16.7 mg L^{-1}, in NH_4-N from 0.6 to 442.5 mg L^{-1}, in NO_3-N from 0.0 to 4.8 mg L^{-1}, and in TN from 5.5 to 450.2 mg L^{-1} (Table 7.3). Outflow concentrations for all thicknesses of WT ranged in DRP from 0.03 to 9.8 mg L^{-1}, in TP from 0.43 to 23.3 mg L^{-1}, in NH_4-N from 51.4 to 307.3 mg L^{-1}, in NO_3-N from 0.0 to 114.0 mg L^{-1}, and in TN from 0.4 to 346.6 mg L^{-1} (Table 7.3). Neither thickness, byproduct, nor their interaction affected ($p > 0.05$) the concentrations of DRP, TP, NH_4-N, NO_3-N, or TN (Table 7.3), when the thicknesses and byproducts were compared together. However, when the thicknesses and the byproducts were compared separately, the DRP concentration was lower ($p < 0.05$) for RM than for WT for the 4- and 12-cm byproduct thicknesses (Table 7.3). Similarly, the NH_4-N concentration was also lower ($p = 0.02$) for RM than for WT for the 8-cm byproduct thickness (Table 7). In addition, the NO_3-N concentration was lower ($p < 0.002$) for RM than for WT for the 8- and 12-cm byproduct thicknesses.

Selection of Byproduct Thickness for On-Farm Containment Structure

Clogging with the broiler dust was observed in all 4 cm-thickness treatments for both byproducts. The 4-cm thickness was not chosen for use in the on-farm containment structure due to the rapid clogging, which visibly restricted water flow through the byproduct. Although there were no differences in outflow concentration among the byproduct thicknesses, the intent of this project was to design a cost-effective treatment system and, therefore, the 8-cm thickness was chosen instead of the 12-cm thickness for use in the on-farm study, based on cost savings to the producer. While there was no cost to obtain the byproducts, there was significant cost to transport and dry both byproducts. Therefore, it was determined that using a smaller containment structure and less byproduct would result in beneficial cost savings to the end user.

Additional Analyses of Outflow from Rainfall Simulation on Byproducts

Concentrations of copper in the RM, RM+dust, and WT+dust ranged from 403 to 2,153 ppb, which exceeded Arkansas industrial stormwater benchmarks of 75.6 ppb (Table 7.4). Concentrations of zinc in the RM, RM+dust, and WT+dust ranged from 1,269 to 1,513 ppb, which also exceeded Arkansas

industrial stormwater benchmarks of 684 ppb (Table 7.4). The sources for these metals were both the byproducts and the broiler house dust. To prevent excess levels of metals from entering runoff, the containment structures were designed to release leachate and store contaminants in the soil below the A horizon. Monitoring subsoil contaminant levels is advisable to ensure that buildup is avoided.

Containment Structure Leachate Collection and Analyses

The outflow concentrations of DRP in all four containment structures was consistently below 0.6 mg L^{-1}, and the outflow DRP concentrations did not vary among trays (Table 7.5) Outflow concentrations of TP, NH_4-N, NO_3-N, and TN differed among containment structures, which is not unusual since each of the containment structures is located at a different fan outlet, and different fans operate for different times throughout a flock grow-out cycle, resulting in different volumes of dust being exhausted onto the each containment structure. Both byproducts had outflow concentrations of TP consistently below 1.5 mg L^{-1}. Outflow from the containment structures filled with RM had an average NH_4-N concentration at least 6.6 times lower, an average NO_3-N at least 2.3 times lower, and an average TN at least 3.2 times lower than outflow from the containment structures filled with WT (Table 7.5).

The containment structures, designed with PVC and vinyl-coated mesh that are resistant to environmental degradation from ultraviolet light, bacteria, and mold, have been in place since April 2013 and have performed as intended and show no signs of weathering. They have been exposed to heavy rainfall up to 7 cm in a 24-hour period, and outdoor temperatures exceeding 38^{o}C. The structures have functioned properly to trap broiler house dust and percolate rain and runoff water. Visual observations of the system during and directly following a rainfall event have shown characteristics in dust deposition and water infiltration similar to that observed in the 56.8-L buckets used in the rainfall simulation study. The dust accumulates on the surface and restricts the infiltration rate of rain and runoff water through the byproduct, but does not pond and overtop the structure. The slowed infiltration rate increases contact time with the byproduct, which results in greater P removal from the dust and water combination. The Savoy study will continue until P saturation occurs or byproducts are clogged with dust and their hydraulic conductivities become too slow for proper operation of the structures, in order to determine how often the byproduct will have to be replaced to continue to effectively remove P. Once saturated with P or clogged,

the byproduct will be removed from the containment structure and will be land applied with broiler litter from house clean-out.

Conclusions

Testing of the iron and aluminum byproducts for their effectiveness in sorbing nutrients from broiler house dust will be useful for current and future design methods for on-farm nutrient reduction practices. For instance, there are numerous ways in which the byproducts can be used for various agricultural applications, such as containment in ponds, containment to intercept runoff in drainage swales, and land application at nutrient sources.

Preliminary findings from the analyses of the leachate from the containment structures indicate they are effective at removing P from broiler house dust prior to the P entering stormwater runoff. Evaluation of the lifespan of the 8-cm thickness of the byproducts in the containment structures will need to be conducted after each containment structure has failed due to clogging or P saturation. To fully evaluate the lifespan of each of the byproducts, studies would be required to compare additional containment structures of byproduct at fan outlets.

Efforts to make the containment structures commercially available, resulting in use of large amounts of WT from Beaver Water District and RM from Bekaert Steel, would reduce the amount of the byproducts being disposed of in landfills. To further reduce the cost to the end-user, efforts are underway to get the structures officially approved by EPA and NRCS for cost-share programs, which could reduce producer cost to at or near zero. New containment structures are being sized for installation on a different broiler facility in northwest Arkansas, and will be displayed as a low-cost, best management practice for water quality.

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Table 7.1. Randomized Layout of Buckets for Rainfall Simulation Study

Replicate	Material	Thickness of Material in Bucket (cm)	Position within the Set
1	WT	4	9
	WT	12	5
	WT	8	4
	WT (control)	12	3
	Dust	n/a	6
	RM	4	1
	RM	8	8
	RM	12	7
	RM (control)	12	2
2	WT	4	13
	WT	12	12
	WT	8	18
	WT (control)	12	16
	Dust	n/a	10
	RM	4	17
	RM	8	15
	RM	12	11
	RM (control)	12	14
3	WT	4	22
	WT	12	25
	WT	8	26
	WT (control)	12	19
	Dust	n/a	27
	RM	4	20
	RM	8	24
	RM	12	23
	RM (control)	12	21

Table 7.2. Coefficient of Uniformity of Rainfall on the Buckets for Three Rainfall Events

Set of Column Buckets	Rainfall 1	Rainfall 2	Rainfall 3	All Rainfalls
	%			
Group 1	85	92	88	95
Group 2	91	92	95	94
Group 3	88	87	83	87

Table 7.3. Byproduct Bucket Study – Phosphorus and Nitrogen Concentrations in Outflow

Product/Statistic	cm	mg L^{-1}				
	Thickness	DRP[#]	TP	NH_4-N	NO_3-N	TN
Dust	n/a	31.70	55.62	156.16	2.00	233.67
RM (control)	12	0.08	0.39	4.39	0.25	10.71
RM	4	0.32	4.94	81.74	1.93	133.45
RM	8	0.20	3.52	38.47	1.67	89.48
RM	12	0.48	5.10	87.80	1.59	130.95
WT (control)	12	0.02	0.22	39.82	8.05	55.11
WT	4	3.42	8.46	96.93	10.89	161.63
WT	8	1.21	7.16	136.04	42.54	211.34
WT	12	1.70	7.72	152.53	22.26	198.70
Two-Way Analysis of Variances P-value*						
Byproduct			0.14			
Thickness			0.89			
Interaction			0.95			
One-Way Analysis of Variance P-value[†]						
RM	4, 8, 12	0.25		0.61	0.90	0.81
WT	4, 8, 12	0.22		0.42	0.35	0.63
RM/WT	4	0.047		0.71	0.14	0.60
RM/WT	8	0.07		0.02	0.001	0.06
RM/WT	12	0.04		0.26	0.002	0.29

[#] Dissolved reactive phosphorus (DRP), total phosphorus (TP), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), and total nitrogen (TN).

* Two-way ANOVA conducted on data with homogeneous variances

[†] One-way ANOVA conducted on data without homogeneous variances

Table 7.4. Concentrations in Leachate from Bucket Study (Major Cations and Trace Elements)

Element	Limit of Detection (LOD)	AR Industrial Stormwater Benchmark Values	Byproduct and Treatment			
			RM (no dust) Avg.	RM + Dust Avg.	WT (no dust) Avg.	WT + Dust Avg.
Aluminum (ppb)	0.60	750.00	0.00	30.33	0.00	195.00
Antimony (ppb)	0.01	none	0.75	0.25	0.13	0.07
Arsenic (ppb)	0.01	169.00	70.22	15.68	2.48	9.36
Barium (ppb)	0.00	none	0.00	0.00	50.43	70.90
Beryllium (ppb)	0.02	130.00	<LOD	<LOD	<LOD	<LOD
Boron (ppb)	1.66	none	78883.40	126650.07	1893.40	2778.40
Cadmium (ppb)	0.00	11.80	0.10	0.07	0.04	0.19
Calcium (ppm)	0.06	none	2760.40	709.40	6.97	2.60
Cerium (ppb)	0.00	none	0.01	0.03	0.02	0.33
Cesium (ppb)	0.00	none	2.36	1.53	0.21	0.88
Chromium (ppb)	0.02	none	5.22	3.41	0.85	6.11
Cobalt (ppb)	0.00	none	3.42	3.40	0.15	3.76
Copper (ppb)	0.02	75.60	538.31	2152.64	3.87	402.98
Lanthanum (ppb)	0.00	none	0.00	0.03	0.01	0.31
Lead (ppb)	0.00	519.00	0.00	0.03	0.16	1.22
Lithium (ppb)	0.01	none	39.82	10.67	0.47	0.38
Magnesium (ppm)	0.00	none	1539.64	344.30	0.58	8.57
Manganese (ppb)	0.02	none	457.73	193.73	1241.39	1803.06
Molybdenum (ppb)	0.01	none	6.43	15.08	0.01	2.99
Nickel (ppb)	0.00	none	22.52	70.95	0.62	73.11
Potassium (ppm)	0.02	none	13.40	209.30	6.33	138.80
Praseodymium (ppb)	0.00	none	<LOD	0.12	0.04	0.15
Rubidium (ppb)	0.00	none	10.83	172.80	15.23	112.03
Selenium (ppb)	0.10	239.00	1.47	3.37	13.96	16.37
Silicon (ppm)	0.02	none	1.33	<LOD	<LOD	<LOD
Sodium (ppm)	0.01	none	579.29	159.29	12.29	47.62
Strontium (ppb)	0.00	none	574.60	133.93	7.33	7.70
Sulfur (ppm)	0.20	none	351.44	461.44	18.14	161.77
Tin (ppb)	0.01	none	0.30	0.18	0.00	0.00
Titanium (ppb)	0.20	none	8.71	4.32	<LOD	13.37
Tungsten (ppb)	0.01	none	0.53	0.40	<LOD	0.20
Uranium (ppb)	0.00	none	0.30	0.28	<LOD	0.02
Vanadium (ppb)	0.02	none	50.50	8.30	8.60	3.59
Zinc (ppb)	1.00	684.00	1269.07	1512.73	245.63	1487.40

Table 7.5. Average Concentrations (mg L^{-1}) in Outflow from Containment Structures Filled with Iron Filter Cake (RM) or Water Treatment Residual (WT)

Analyte*	Containment Structure Byproduct and Location				P-value[#]
	RM Fan 1	WT Fan 2	RM Fan 3	WT Fan 4	
DRP	0.42	0.26	0.57	0.20	0.20
TP	0.87	0.37	0.89	0.36	0.01
NH_4-N	8.53	59.41	5.46	36.23	<0.001
NO_3-N	9.66	37.29	10.90	25.14	0.03
TN	22.39	83.64	18.75	61.10	<0.001

* Dissolved reactive phosphorus (DRP), total phosphorus (TP), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), and total nitrogen (TN)

[#] P-value result for effect of containment structure

Figure 7.1. Schematic of Containment Structure Design

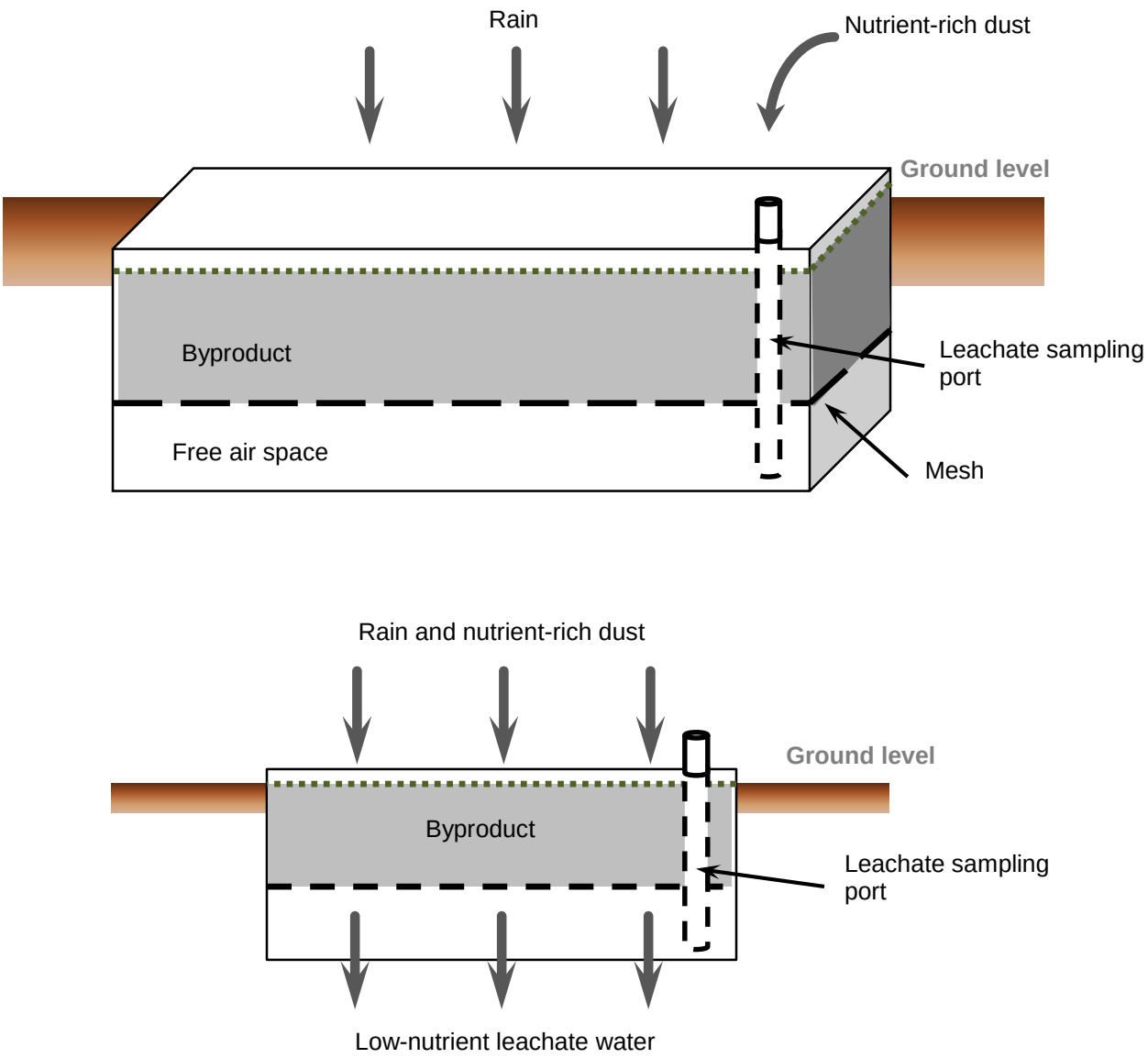

Figure 7.2. Schematic of Stacked 56.8-L Buckets used in Rainfall Simulation Experiment

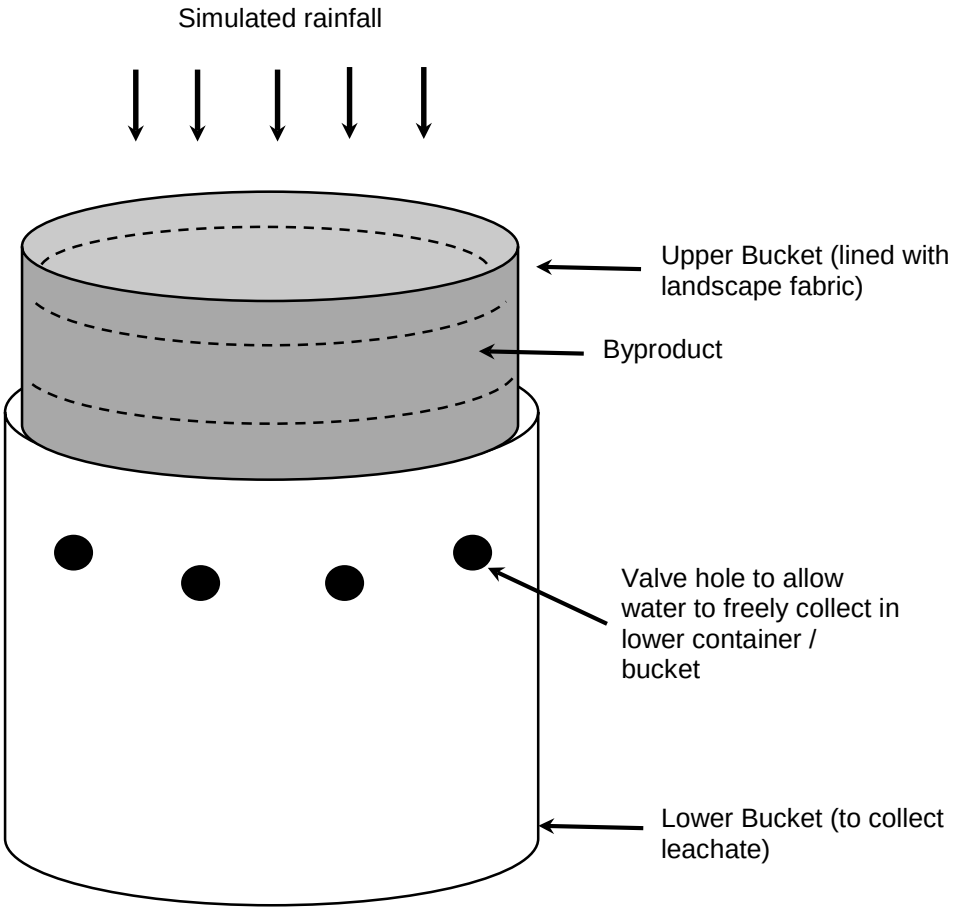

Figure 7.3. Assignment of Buckets into 3 Groups (white, gray, and black) based on SAS Randomization Plan

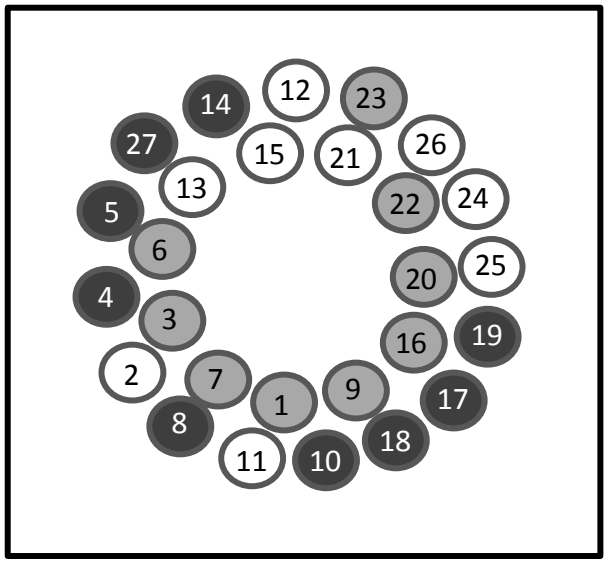

Image 7.1. Containment Structure as Designed (without landscape fabric and byproduct)

Herron, 2013.

Image 7.2. Containment Structure with Liner Installed at Savoy Broiler Production Facility

Herron, Sheri. 2013.

Image 7.3. Containment Structure Installed at Savoy Broiler Production Facility

Herron, Sheri. 2013.

Image 7.4. Actual Layout of Buckets under Rainfall Simulator based on Rainfall Uniformity Test

Herron, Sheri. 2013.

CHAPTER 8

PROJECT CONCLUSIONS

PROJECT CONCLUSIONS

The nutrients that contribute to increased rates of eutrophication in rivers and lakes, phosphorus (P) and nitrogen (N), are present in broiler house dust (BHD). There were distinct differences among integrator producer facilities in nutrient concentrations of dust collected. This was likely due to differences in dietary mixtures used by integrators, bedding material, and other in-house management protocols that each producer uses. Therefore, facilities producing for different integrators should be evaluated for their unique potential to contribute P and N to stormwater runoff. Although the concentrations of total phosphorus (TP), water extractable phosphorus (WEP), and total nitrogen (TN) in BHD varied between facilities, these concentrations were consistently greater in the BHD than in the broiler litter (BL) from the same facility. Additionally, the moisture content of the BHD was approximately half that of the BL from the same facility. Due to the variability of moisture content, TP, WEP, and TN between BHD and BL, research that has been conducted on BL to evaluate nutrient transport in stormwater runoff cannot be considered equivalent to using BHD.

To evaluate the potential for nutrient enrichment in runoff from dust deposited on the ground adjacent to fans on a broiler house, artificial rainfall simulations were conducted five times throughout a year, following bird removal, on 1.5 m by 2.0 m plots, at 7 cm hr^{-1} until 30 minutes of surface runoff was collected. Although the subject facility is not discharging directly into a waterway, the nearest waterway is the Illinois River. The Illinois River is a fresh-water basin and P is the controlling nutrient for eutrophication, so the greatest concern is contribution of P compounds. Oklahoma has set a target limit of 0.037 mg L^{-1} TP for the Illinois River when it crosses the state line from Arkansas into Oklahoma. Additionally, ammonium nitrogen (NH_4-N) discharges are a concern due to toxicity to aquatic animals, although no limits have been set for the Illinois River for this parameter. It is important to recognize that runoff concentrations from each fan plot, regardless of the season, were consistently above 1.0 mg L^{-1} TP, and 3.9 mg L^{-1} NH_4-N. If a facility is proximate to a waterway, broiler house fan dust runoff concentrations at the nutrient source could be elevated and pose a threat to water quality.

The plot studies evaluated the potential of nutrient losses at the source. To quantify losses from an entire production area, runoff was automatically sampled for storm events between April 2012 and

August 2013 at two culverts draining the land between broiler production houses. Runoff volumes were two-fold greater at the culvert draining the area with the road, which created a larger impervious surface area. Alternatively, the drainage area with no road and good vegetative cover allowed for a significant volume of water, along with nutrients, to infiltrate into the soil. At facilities with drainage areas dominated by less permeable surfaces, the risk of nutrient enrichment of runoff is greater than those dominated by permeable soil and grass cover. The culverts where runoff was sampled were at the edge of the facility. Concentrations of nutrients in runoff at the culverts were notably lower than concentrations of nutrients in runoff from fan plots receiving simulated rainfall. However, total annual P loads were numerically greater for both culverts (7.9 kg ha^{-1} yr^{-1} at C2A and 1.5 kg ha^{-1} yr^{-1} at C1A) than typical losses from northwest Arkansas pastures receiving broiler litter at a rate of 1.3 kg ha^{-1} yr^{-1} (1.5 ton litter $acre^{-1}$ yr^{-1}). Hence, if a broiler production facility is located adjacent to a waterway, there is risk of nutrient enrichment of the waterway from runoff from the land around the production area if there are not sufficient flow and/or nutrient reduction measures in place.

Two industrial byproducts, iron filter cake (RM) and alum water treatment residuals (WT), were evaluated for use in on-farm P removal technology. The ≤2-mm particle-size fraction treatment combination of RM and WT were tested in a batch equilibration study. Both byproducts had large P-adsorption capacities (P_{max}), 25 and 10 mg P g^{-1}, respectively, in spite of the P adsorbed to the raw byproducts when they were obtained. The P_{max} value of each byproduct is important for estimating the lifespan of any material that has the potential to be used for on-farm P removal systems.

Hydraulic conductivity (HC) and P removal studies were conducted for the RM and WT byproducts' particle-size fraction treatment combinations of ≤2-, ≤6-, and ≤12.5-mm diameter. Particle-size fraction treatment combinations of ≤6-, and ≤12.5-mm were sufficient to transmit the baseline 25-year, 24-hour storm. The P adsorption column study allowed testing of the three particle-size fraction treatment combinations of each byproduct in a manner more closely resembling field conditions than the batch equilibrium method used for the isotherm analyses. The ≤2- and ≤6-mm particle-size fraction treatment combinations removed greater than 50% of P in solution, indicating viability for use in on-farm P removal systems. Successful design and operation of an on-farm P removal system utilizing the RM and WT byproducts would be dependent on both the HC and P removal potential of the select particle-size

fraction treatment combination. Field testing of any design would be necessary to properly evaluate and ensure effectiveness.

Containment structures for the ≤6-mm particle size fraction treatment combination of RM and WT byproducts were installed outside, below fan outlets at a broiler production facility. Preliminary findings from the analyses of the leachate from the containment structures indicate they are effective at removing P from broiler house dust prior to the P entering stormwater runoff. Evaluation of the lifespan of the 8-cm thickness of the byproducts in the containment structures will need to be conducted after each containment structure has failed due to clogging or P saturation. To fully evaluate the lifespan of each of the byproducts, studies would be required to compare additional containment structures of byproduct at fan outlets.

Efforts to make the containment structures commercially available, resulting in use of large amounts of WT from Beaver Water District and RM from Bekaert Steel, would reduce the amount of the byproducts being disposed of in landfills. To further reduce the cost to the end-user, efforts are underway to get the structures officially approved by EPA and NRCS for cost-share programs, which could reduce producer cost to at or near zero. New containment structures are being sized for installation on a different broiler facility in northwest Arkansas, and will be displayed as a low-cost, best management practice for water quality.